A Study on Impact of Humps (Bumps) on Vehicular Movement

A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of

Master of Technology

by

Neeraja Chinta

to the

DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

INDIA

May, 2005

Certificate

This is to certify that the work contained in the thesis titled **A Study on Impact of Humps on Vehicular Movement**, by **Neeraja Chinta**, has been carried out under my supervision and this work has not been submitted elsewhere for a degree.

May, 2005

Dr. Partha Chakroborty
Department of Civil Engineering,
Indian Institute of Technology,
Kanpur

Acknowledgment

I am deeply indebted to my thesis supervisor, Dr. Partha Chakroborty for his inspiring guidance, valuable suggestions and overall supervision throughout the progress of my work. The way he made me think and work has an everlasting impact on my career and life. I express my deep sense of gratitude to my thesis supervisor for giving me valuable advices and knowledge and making my life at IIT Kanpur a memorable one.
I express my sincere thanks to Dr. Animesh Das and Dr. B.R.Marwah for enriching my knowledge in the courses taught by them. I am grateful to the Transportation Engineering Laboratory staff for their cooperation and help. I am thankful to Dr. Bajpai for helping me in repairing the radar gun.
I am thankful to my classmates and seniors, Ranja, Aravind, Durgesh, Shukla, Amit, Ujjal and Akhilesh for being friendly and cooperative during the surveys in IITK.
I am specially thankful to my juniors Sandeep, Kalhan and Rajib for help and cooperation during the surveys in IITK. Without their great cooperation I would not have completed my thesis within time.
I am grateful to my friends Jaya, Trishi, Meera, Pavani, Pallavi, Ujjwala, Prachi, Ram, Kiran, Srikanth who were always there to support and encourage me in situations and I express my thanks to Sutapa and Antara who made my stay at IIT Kanpur a memorable one.
I am deeply indebted to my family and friends for their love and constant encouragement which helped me to make all this possible.

Neeraja Chinta.

Abstract

Controlling vehicular speeds is important in traffic management. One way of controlling speed is to use static speed control devices like humps. In order to know impacts of a hump, detailed survey of vehicular behavior near humps should be done. In this work, area of study is considered as IIT Kanpur. In the present study impact parameters are considered as, speed at hump, speed reduction, deceleration, and acceleration. In the present work, to know these impact parameters different types of survey are conducted, namely, speed profile survey, deceleration profile survey, and acceleration profile survey. From the obtained impact parameters, relations between hump geometry (hump height) and impact parameters are developed. The relationships are developed for both two and four wheelers separately. Linear and non-linear models are developed for impact parameters, speed at hump, and speed reduction. Only linear models are developed for deceleration and acceleration. Better relations are obtained with speed reduction and deceleration compared to others.

Contents

List of Tables

List of Figures

Chapter 1

Introduction

As the drivers are moving at higher speeds due to improved vehicular technology, the speeds should be controlled. In order to control these speeds, static speed control devices are used. Different types of static speed control devices are speed hump, speed bump, speed cushion, etc. One of the widely used static speed control device is a speed hump, a raised area on the roadway. A hump impacts the movement of vehicles in different ways. In order to study these different impacts, a detailed survey need to be conducted. Two important parameters are involved in design of road humps, hump geometric design and hump spacing. To obtain impact parameters, surveys such as speed profile survey, deceleration profile survey and acceleration profile survey have to be conducted.

The purpose of this work is to study the impact parameters of a hump, like speed at hump, speed reduction, deceleration and acceleration and to develop the relationship between the hump impact parameters and hump geometry.

This thesis has been divided into five chapters of which this is the first. In the second chapter the exact problem this thesis has addressed has been described. The literature on humps is presented in Chapter 2. In the third chapter, the types of survey undertaken here, like the speed profile survey, deceleration profile survey, and acceleration profile survey are described. The results obtained from these surveys are presented.

In the fourth chapter, various relationships are developed between hump geometry and hump impact parameters such as speed at hump, speed reduction, deceleration, and acceleration. Comparison of the developed models with the previous models obtained from the literature is also done. Finally, the fifth chapter presents the summary of work done in this thesis highlighting the salient feature.

Chapter 2

Problem Statement and Literature Review

This chapter describes the problem handled in this thesis. The chapter also describes the existing work done on the problem.

2.1 Problem Statement

The problem studied here is the impact of road humps on vehicular traffic. A hump is laterally raised portion of the road meant to serve as static speed control device. Figure 2.1 shows how humps are placed on roads and Figure 2.2 shows the different types humps. For detailed description of other kinds of static speed control devices one may refer to speed cushions, speed tables, rumbler, etc in Webster [3], Webster and Mackie [6] and Barbosa et al [8].

As mentioned before the primary purpose of a hump is to reduce the speed of vehicle to desired levels. In order to achieve this, the hump impacts vehicular movement in many ways. These impacts can be studied by studying the following parameters (henceforth referred to as impact parameters).

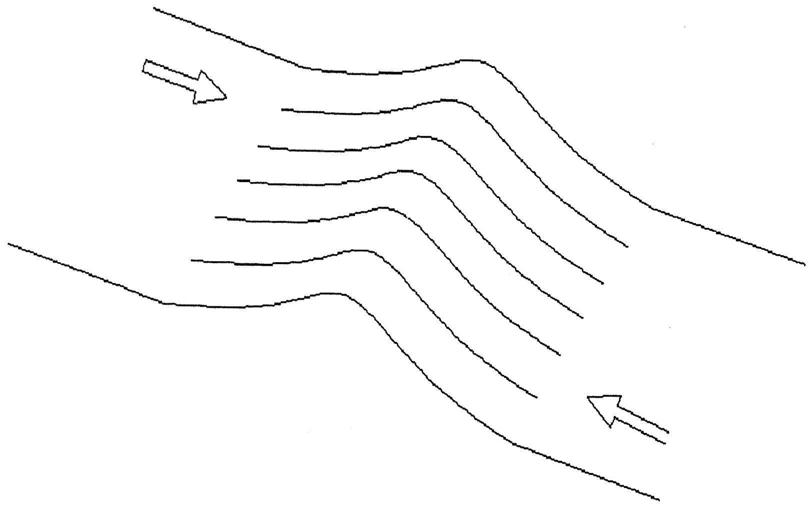


Figure 2.1: Positioning of a hump on a road

1. Speed at humps - a hump tries to control speed and hence the speed of vehicles at hump is an important measure of a humps impact on vehicular movement.
2. Extent of speed reduction at humps - a hump will cause vehicles to reduce their speeds. The extent by which different vehicles (approaching the hump at different speeds) reduce their speed while crossing the hump also needs to be studied.
3. Discomfort at humps - vehicles crossing humps always face a discomfort arising primarily from acceleration in vertical directions. This discomfort should be studied.
4. Decelerations while approaching hump - different vehicles may employ different deceleration rates while approaching the hump. Since the rate at which speeds are changed affects the flow of traffic stream and also other aspects like increased accident potential, increased fuel consumption, etc. This aspect should be studied.
5. Accelerations after crossing the hump - the acceleration rates employed by different vehicles after crossing the hump also needs to be studied for the reasons similar to those mentioned in previous point.

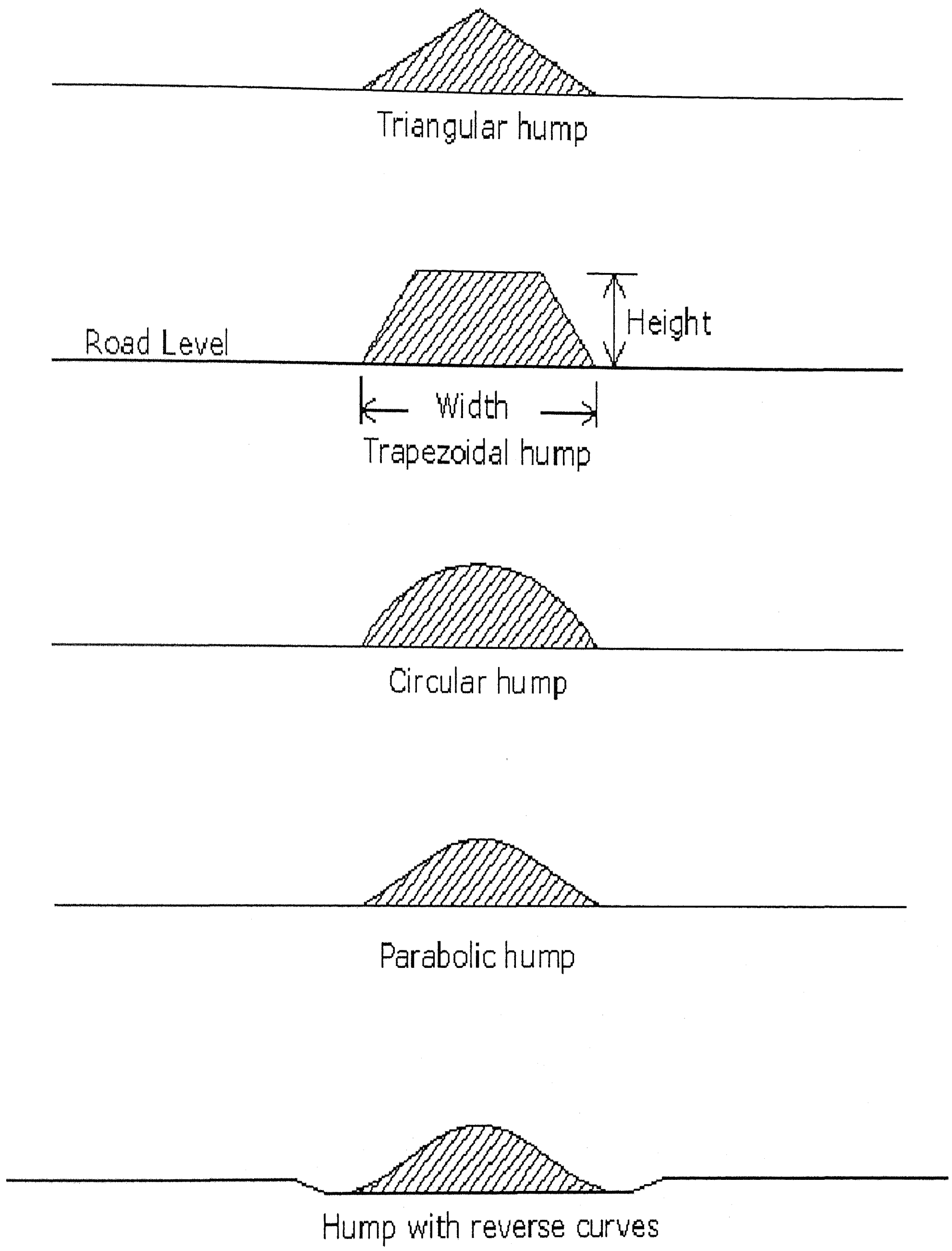


Figure 2.2: Different types of hump

6. Impact zone - every hump affects the speed of vehicles over a certain distance. For example, a vehicle approaching a hump may start reducing its speed from a distance x_d from the hump; a same vehicle may take a distance x_a after crossing the hump to regain its initial speed. The distance $x_d + x_a$ can then written as impact zone of hump. This feature must also be studied in order to determine how a particular hump affects vehicular movement.

All the points, mentioned here will give different results for different types of vehicles. Hence, the study of these parameters should also include different vehicle types.

In this thesis, the study of impact of humps on vehicular motion is studied. The hump type considered is parabolic. The reason for concentrating only on parabolic hump was because (as mentioned later) the study area only had humps of this kind. The impact parameters studied here are

- Speed at humps
- Extent of speed reduction at humps
- Decelerations while approaching hump
- Accelerations after crossing the hump

These parameters are studied for two different vehicle types, namely, two wheelers (including scooters, bikes, moped, etc.) and four wheelers (including older model cars like ambassador, fiat, etc, compact cars like maruti, santro, zen, etc, mid- sized sedance like ikon, esteem, astra, etc and vans like qualis, sumo, etc.). The parameters vehicular discomfort was not studied due to lack of requisite equipment. The parameter impact zone was not studied as the study area did not have stand alone humps for which impact zone can be clearly measured.

This thesis not only measures the impact parameters but also tries to relate hump geometry to these impact parameters. This is important as such relations will allow an engineer to choose a proper hump geometry given requirements of particular site.

The importance of study, the impact of humps as always been felt. The next section describes some of the earlier studies relating to the problem described here.

2.2 Literature Review

One of the first studies on humps, their design and impact, was by Watts [1]. This study concentrated the designing of hump which is not too uncomfortable yet effective, toward alerting the speeding drivers. Watts suggested a 3.6 m wide and 100 mm high circular hump as an ideal design. No effort was made to relate hump geometry to any of the impact parameters mentioned earlier. Later Baguley [2] studied the effect of hump spacing on average speeds on the road for hump designs motivated by Watts' suggestion. In effect this study concentrated on the impact zone of humps of a particular design.

Webster [3] and Lines [4] also report studies on relationship between hump spacing and average as well as 85^{th} percentile speed. These relations, from the early 90's, when compared to Baguley's [2] (from early 80's) show effect of improvements in vehicular technology on the impact of humps. Their study, unlike Baguley [2] also include flat top humps. Like the studies of Watts [1] and Baguley [2] neither Webster [3] nor Lines [4] developed any relations which relate any of the impact parameters to hump geometry. In the report by Webster, a study on impact of humps on accidents is also provided. Webster and Mackie [6] provided a similar study in a later report also.

One of the first papers, to relate speed at humps to hump geometry was by Fwa and Tan [5]. In their study they looked at 28 humps; they did not differentiate between different hump profiles (like circular versus flat topped etc.). They found that hump geometry is better characterized by area to width ratio. The area of hump is defined as the area of hatched portion shown in Figure 2.2 . The goodness of fit (R^2) of their relations however were always less than 0.7. One of the problems with their relation is the suggestion that area to width ratio should be used to characterize hump geometry.

This is so because determining area of a hump requires detailed data on the hump geometry. Further, it is felt that drivers' reduce speed at hump because the humps appear as impediments to travel. Given this understanding it is difficult to explain how drivers' can perceive the area of a hump. It is also felt that the area to width ratio will be strongly correlated to the height of the hump (for example, if the hump profile is assumed to be triangular then the ratio is exactly equal to half the height) and hence the authors should have tried height alone as variable.

In IRC 99, it is suggested that the rounded hump of 3.7 m width and 0.10 m height is preferred for crossing speeds of 25 kmph. It is also been suggested that the distance between one hump to other hump vary from 100 m to 120 m to keep speeds low throughout section. However, IRC gives no relations between hump geometry and its impact on vehicular movement. Even its guidelines are very sketchy. For example, if one wants to reduce speeds to 35 kmph there are no guidelines on the hump geometry.

In a recent study, Barbosa et a'l. [8] have tried to develop a relationship between the speed at any point on the road to the speed at which vehicles enter the road, the distance of the vehicle from neighboring humps, and the hump types. Surprisingly, they did not relate the speed to hump geometry.

The review of literature shows that not much work has been done to relate hump geometry to the impact parameters described earlier. Hence, in this thesis an attempt has been made to relate the four impact parameters mentioned to hump geometry.

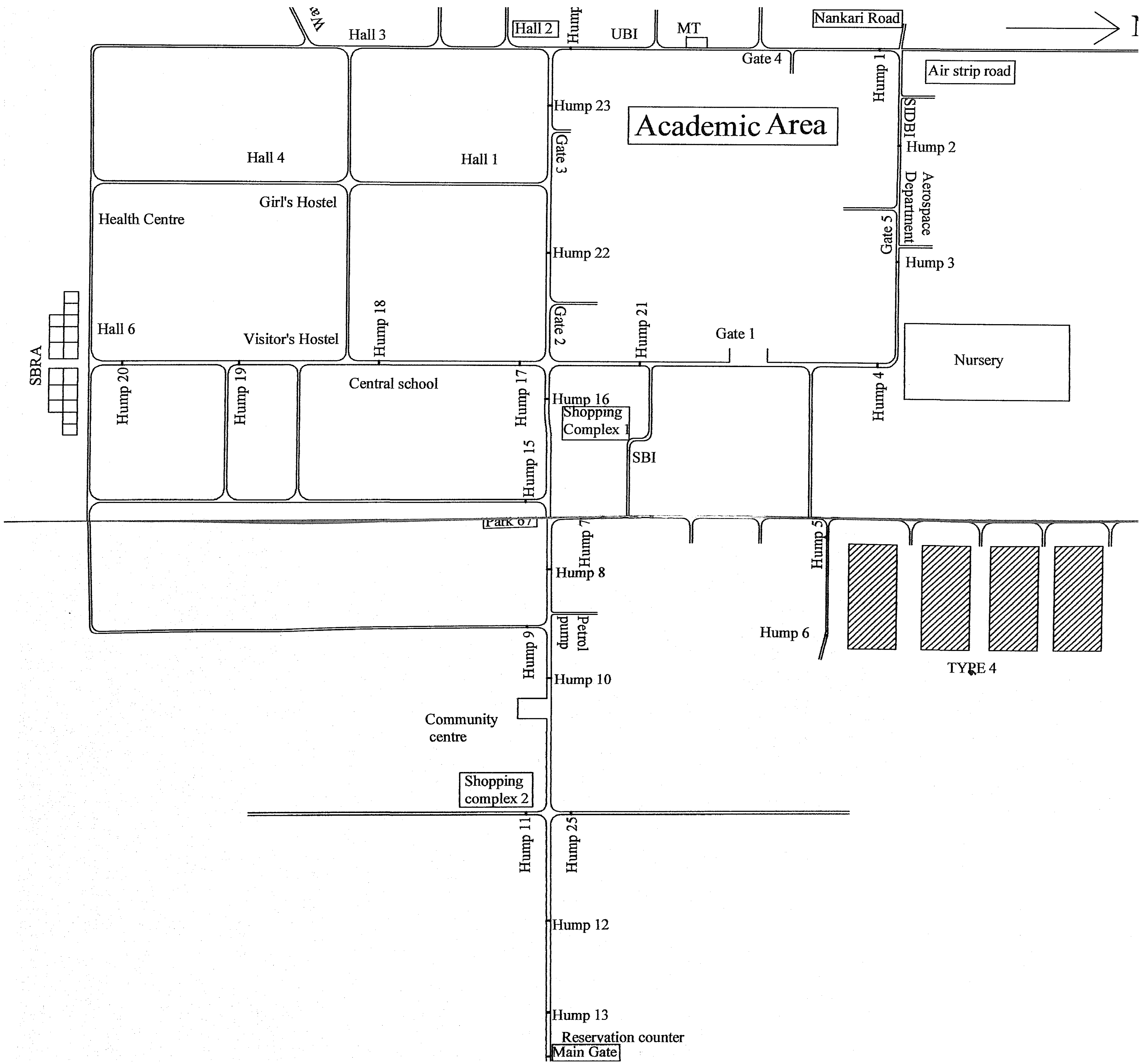
Chapter 3

Study of Vehicular Behavior near Humps

In order to determine impacts of road humps on vehicular traffic, it is necessary to study the impact parameters. The impact parameters studied here are speed at humps, extent of speed reduction at humps, decelerations while approaching the hump and accelerations after crossing the humps. For collecting the data on the impact parameters, various surveys are conducted. Surveys are conducted on different roads of IIT Kanpur. This chapter is divided into three sections. The first section describes the sites at which survey was done. The second section describes the types of surveys that are done at each site. The last section presents the observations.

3.1 Hump locations, shapes and sizes

In this section, the humps at which the surveys were done are discussed. The discussion includes, their location, shape and size. In all 25 humps were initially included in the study area. All of these humps are located inside IIT Kanpur campus. Their locations are shown in Figure 3.1.



Nankari Road
Air strip road
Hall 3
Hall 2
UBI
MT
Gate 4
Hump 1
Academic Area
SIDBI
Hump 2
Aerospace Department
Gate 5
Hump 3
Hump 23
Gate 3
Hump 22
Gate 2
Hump 21
Gate 1
Nursery
Hump 4
Hall 4
Hall 1
Girl's Hostel
Health Centre
Hall 6
Visitor's Hostel
Hump 18
SBRA
Hump 20
Hump 19
Central school
Hump 17
Hump 16
Shopping Complex 1
SBI
Hump 15
Hump 7
Hump 8
Hump 5
Hump 6
TYPE 4
Petrol pump
Hump 9
Hump 10
Community centre
Shopping complex 2
Hump 11
Hump 25
Hump 12
Hump 13
Reservation counter
Main Gate

While studying the impact of the hump parameters it is important to realize that a driver may reduce his/her speed not only because of the hump but due to various other reasons also. These reasons include the presence of cross roads, other humps, etc. These description of the humps are given in Tables 3.1 and 3.2 along with extra other features. In the table the following terminology is used to describe a hump: HaaB, where H refers to the word "Hump", aa is a two digit number indicating the hump number (they are the same as those shown in Figure 3.1) and B is capital alphabet indicating one of the cardinal directions (like, N, S, E or W). Thus all information on H12E refers to Hump 12 for eastbound (or towards Main gate) traffic. Notice the same hump may have different characteristics for different travel directions. In the given Tables 3.1 and 3.2, the notation used is given here,

D_u^h = Distance from nearest upstream hump in metres

D_d^h = Distance from nearest downstream hump in metres

D_u^i = Distance from nearest upstream intersection in metres

D_d^i = Distance from nearest downstream intersection in metres

- no upstream hump or no down stream hump.

Next the shape and size of each of these humps were measured and recorded. In order to determine this shape and size the height of the road surface measured at 33 points. These points are schematically shown in Figure 3.2 as black dots. The points are also named 1 to 33. Heights were not measured for two humps in study area, one is rumbler and other is on a sharp curve.

The data related to the location and height of each of these points for each of the 23 humps are provided in
http://www.iitk.ac.in/transEL/hump_data.htm.

Table 3.1: Location of humps

Hump	Road width	Traffic	D^h_u	D^h_d	D^i_u	D^i_d
H14W	6m	High	-	98	5	368
H14E	6m	High	98	-	368	5
H13W	6m	High	98	130	103	270
H13E	6m	High	130	98	270	103
H12W	6m	High	130	352	233	140
H12E	6m	High	352	130	140	233
H10W	6m	High	352	162	182	62
H10E	6m	High	162	352	62	182
H8W	6m	High	162	287	72	61
H8E	6m	High	287	162	61	72
H16W	6m	High	287	209	132	34
H16E	6m	High	209	287	34	132
H22W	6m	High	209	210	140	85
H22E	6m	High	210	209	85	140
H23W	6m	High	210	-	97	68
H23E	6m	High	-	210	68	97
H4S	6m	medium	-	338	12	80
H4N	6m	medium	338	-	80	12
H21S	6m	medium	338	171	230	15
H21N	6m	medium	171	338	15	230
H17S	6m	medium	171	200	22	232
H17N	6m	medium	200	171	232	22
H18S	6m	medium	200	200	222	32
H18N	6m	medium	200	200	32	222
H19S	6m	low	200	165	72	3
H19N	6m	low	165	200	3	72

Table 3.2: Location of humps

Hump	Road width	Traffic	D_u^h	D_d^h	D_u^i	D_d^i
H20S	6m	very low	165	-	134	43
H20N	6m	very low	-	165	43	134
H3W	3.5m	very low	-	167	133	290
H3E	3.5m	very low	167	-	290	133
H2W	3.5m	very low	167	-	300	123
H2E	3.5m	very low	-	167	123	300
H5S	3.5m	very low	-	340	23	24
H5N	3.5m	very low	340	-	24	23
H7S	3.5m	low	340	-	55	29
H7N	3.5m	low	-	340	29	55
H1S	3.5m	verylow	-	438	15.5	158
H1N	3.5m	verylow	438	-	158	15.5
H24S	3.8m	high	438	-	107.5	12.5
H24N	3.8m	high	-	438	12.5	107.5
H25S	3.5m	verylow	-	62	75	21
H25N	3.5m	verylow	62	-	21	75
H11S	3.8m	verylow	62	-	21	33
H11N	3.8m	verylow	-	62	33	21
H9S	3.8m	verylow	-	-	16	31
H9N	3.8m	verylow	-	-	31	16
H15S	4.3m	verylow	-	-	16	31
H15N	4.3m	verylow	-	-	31	16
H6W	3.5m	verylow	-	-	267	12
H6E	3.5m	verylow	-	-	12	267

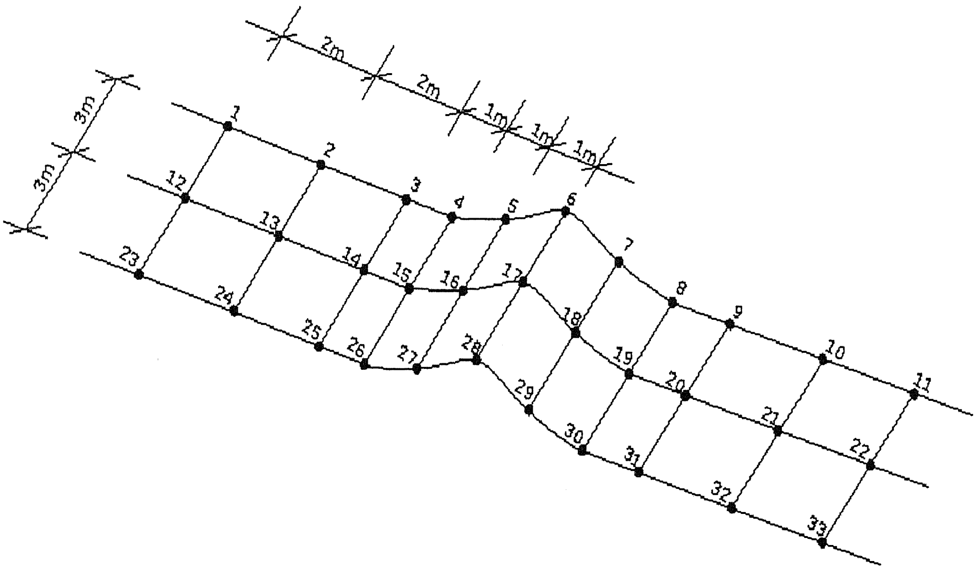


Figure 3.2: Hump geometry survey

3.2 Types of surveys

As mentioned earlier data on various hump impact parameters need to be collected. In this thesis the following data are obtained directly from on-site observations on speed at or near humps. These observations provide information on speed profile, deceleration rates and acceleration rates. However, the data collection strategy varies slightly while collecting data for speed profile of vehicles, deceleration rates, acceleration rates, etc. These are explained in the following subsections.

3.2.1 Speed profile survey

In this survey, speeds are measured using four radar guns at four points near a hump. These points are marked A through D and shown in Figure 3.3. The reason for using four was that only four radar guns were available. Only speeds of unimpeded vehicles (vehicles which are not disturbed by other vehicles pedestrians and other obstructions) are taken. The measured speeds are then noted on data sheets. A sample data sheet is shown in Figure 3.4. The points on the data sheet where speed is collected referred to as Point 1, or Point 2, etc. In this thesis these points are referred as Point A (for Point 1), Point B (for Point 2), etc. Theses points are defined in Figure 3.3. Data are collected separately for two wheelers and four wheelers. Further, in order to obtain larger number of unimpeded vehicles surveys are done when traffic volumes are low. A total of 224 manhours of survey was done to collect data on speed profile. This data is used to determine the speed at hump, S_h. The value of $S_h = V_C$, the speed of the vehicle at C. This data can also be used to study the speed reduction of vehicles due to humps. The speed reduction, S_r is obtained using $S_r = V_A - V_C$ where, V_i is the speed at location i.

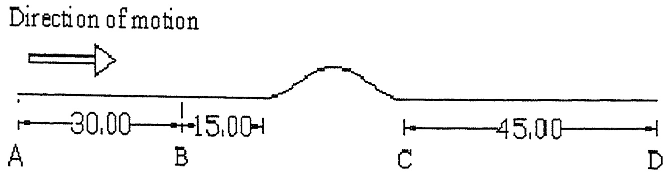


Figure 3.3: Speed profile survey

3.2.2 Deceleration profile survey

In this survey, speeds are measured using four radar guns at three points upstream of the hump and at one point just after the hump. These points are marked A through D and shown in Figure 3.5. The rest of the procedure for collecting and recording speed data is the same as that described in the previous sub-section. A total of 72 manhours of survey was done to collect data on deceleration profile. This data is then used to determine the deceleration rates employed by vehicles at A, B and C. These deceleration values can be determined using the following equation:

$$d_{i\to j} = \frac{(V_i^2 - V_j^2).(25)}{(x_{ij}).(648)}$$

where,

$d_{i\to j}$ is the average deceleration between i and j in m/s^2

V_i is the speed at i in kmph

x_{ij} is the distance between i and j in m

3.2.3 Acceleration profile survey

In this survey, speeds are measured using four radar guns at one point just after the hump and at three points downstream of the hump. These points are marked A through D and shown in Figure 3.6. The rest of the procedure for collecting and recording speed data is the same as that described in the previous to previous sub-section. A total of

Speed data at speed humps in IIT Kanpur

Name: Sandeep Timings: 9,30 to 10-00 Date: 07-01-05
Hump: 2.2 Direction: Hall 2 to [illegible] Point: 4

	2 wheelers			4 wheelers			3 wheelers
S.no	Bikes	Scooters	Mopeds	Type 1	Type 2	Type 3	
1	[illegible] HHS	32 bc			25 omni	34 qualis	
2	40 HHS	34 LML			28 omni	42 [illegible]	
3	25 [illegible]	24 NOVA			36 omni	21 [illegible]	
4	[illegible] hp	31 bc			32 [illegible]	32 baleno	
5	24 HHS	36 bc			31 [illegible]		
6	31 [illegible]	15 bc					
7	[illegible] HHP	23 bc					
8	[illegible]	28 bc					
9	22 bc	27 LML [illegible]					
10	25 hhp	28 bc					
11	28 HH CD	29 bc					
12		29 LML					
13		40 bc					
14		23 Spirit					
15		23 LML					
16		~~25 bc~~					
17							
18							
19							
20							
21							
22							

TYPE 1:Ambassador, Fiat
TYPE 2: Maruti 800,Van, Zen, Santro, Indica, Alto, Wagon R, Tata Sumo, Qualis, Jeep
TYPE 3: Ikon, Benz, Esteem, Opel Astra, Corsa, Hundai Accent
Bikes: HH, Yamaha Crux, Pulsar, Ambition, TVSCentra, Victor, Bajaj4S, LMLFreedom, Kawasaki caliber, Boxer, Suzuki Samurai
Scooters: Bajaj Chetak, 150, LML Vespa, Scooty, Sunny, Khonda, Honda Dio

Figure 3.4: Data sheet

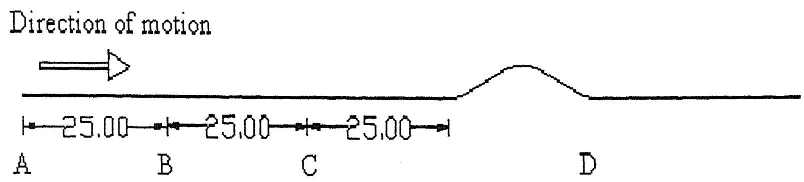


Figure 3.5: Deceleration profile survey

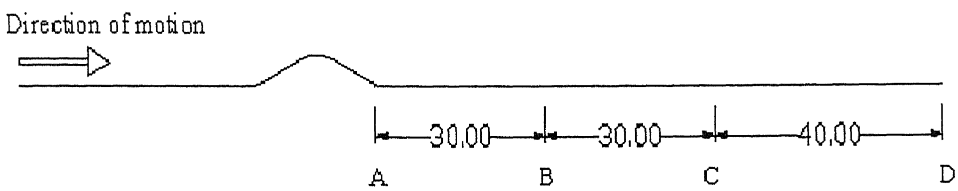


Figure 3.6: Acceleration profile survey

72 manhours of survey was done to collect data on acceleration profile. This data is then used to determine the acceleration rates employed by vehicles at A, B and C. These acceleration values can be determined using the following equation:

$$a_{i \to j} = \frac{(V_j^2 - V_i^2).(25)}{(x_{ij}).(648)}$$

where,

$a_{i \to j}$ is the average acceleration between i and j in m/s^2

V_i is the speed at i in kmph

x_{ji} is the distance between i and j in m

3.3 Observations

A reconnaissance survey was conducted at all humps to determine the proportion of unimpeded vehicles crossing the hump. Based on this survey, and the fact that humps of different geometry needs to be studied the following humps are selected for further investigations: H12W, H10W, H10E, H8W, H8E, H22W, H22E, H21S, H21N, H18S, H18N, H19S, H19N, H2W, H2E, H3W, H3E, H5S and H5N.

As described earlier three different surveys were done, namely speed profile survey, deceleration profile survey and acceleration profile survey. These surveys were done for two wheelers and four wheelers and at the humps mentioned earlier.

Here few representative observations are presented. More are presented in the next chapter while describing some of the analysis done using the observations. However, a comprehensive data base of all the information may be found in
http://www.iitk.ac.in/trnsEL/hump_data.htm

3.3.1 Observations on speed profile

Observations on speed profile show that the average speed profile for either the two wheelers or the four wheelers take the shape shown in Figure 3.7.

As an example Figures 3.8 and 3.9 show some speed profiles collected at H12W for two wheelers and four wheelers respectively.

3.3.2 Observations on deceleration profile

Observations on deceleration profile show the general trend given in Figure 3.10.

As an example Figures 3.11 and 3.12 show some deceleration profiles collected at H12E for two wheelers and four wheelers respectively.

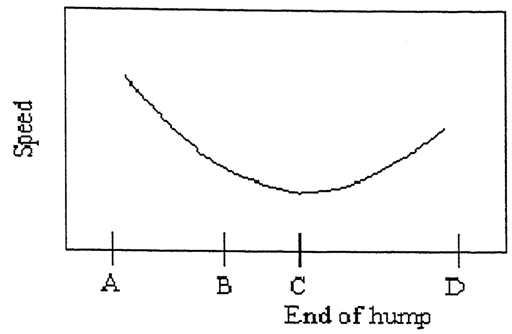


Figure 3.7: Typical shape of a speed profile near hump

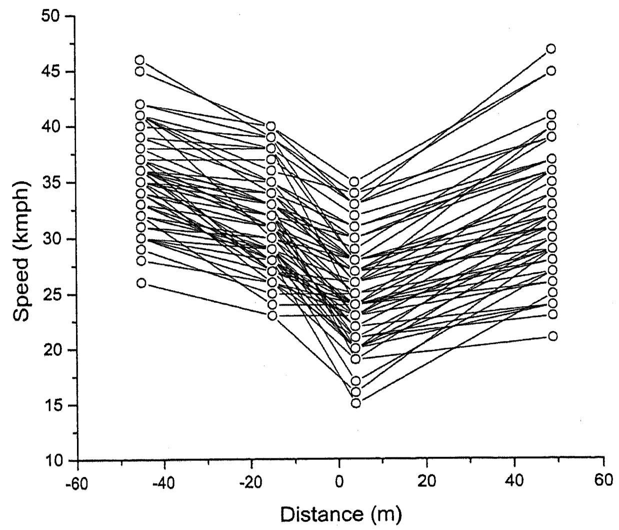


Figure 3.8: Speed profiles for two wheelers of H12W

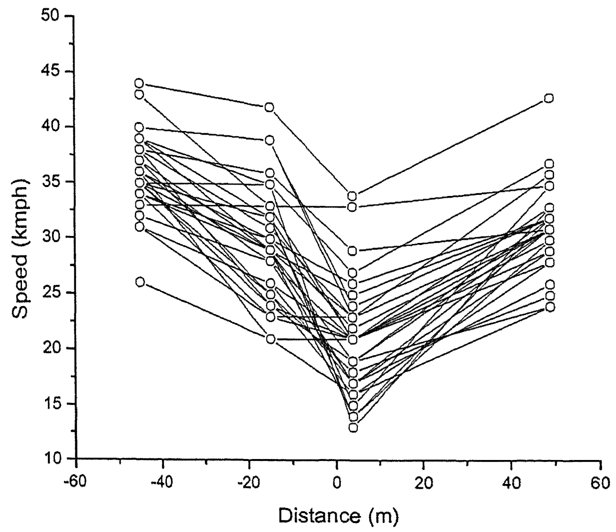


Figure 3.9: Speed profiles for four wheelers of H12W

The other parameters on deceleration have been used in the analysis of the data and are presented in the next chapter.

3.3.3 Observations on acceleration profile

Observations on acceleration profile show the general trend given in Figure 3.13.

As an example Figures 3.14 and 3.15 show some accelerations profiles collected at H12W for two wheelers and four wheelers respectively.

The other parameters on acceleration have been used in the analysis of the data and are presented in the next chapter.

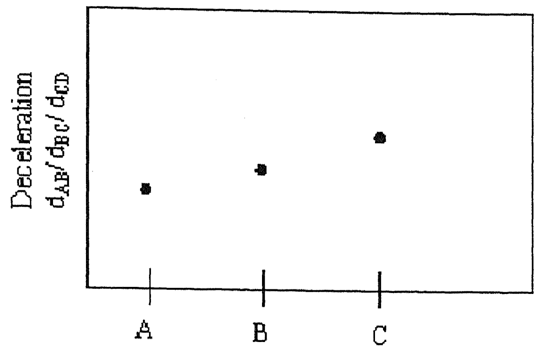


Figure 3.10: Typical shape of a deceleration profile near hump

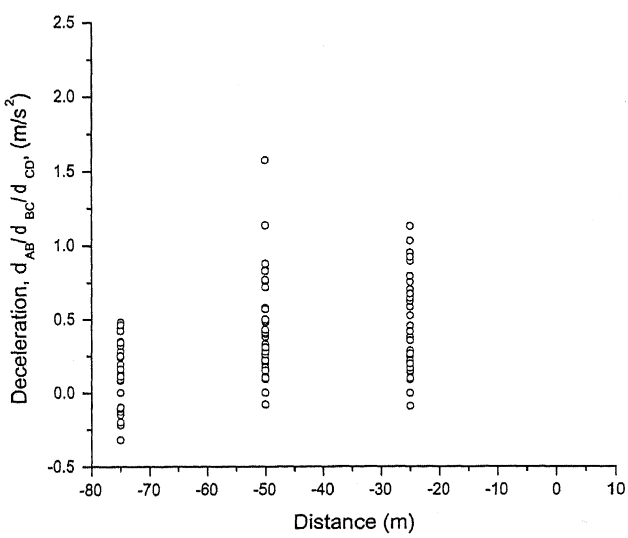


Figure 3.11: Deceleration profiles for two wheelers of H12E

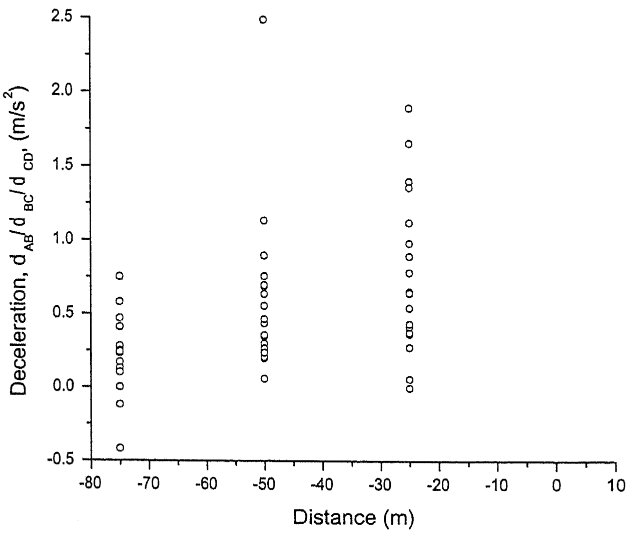


Figure 3.12: Deceleration profiles for four wheelers of H12E

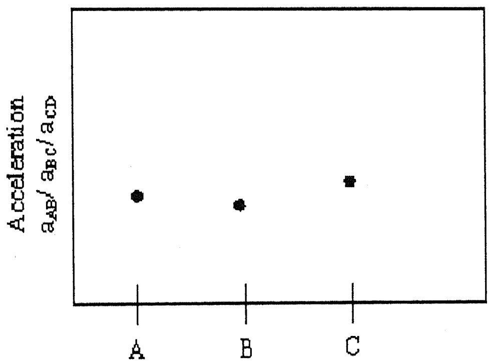


Figure 3.13: Typical shape of a acceleration profile near hump

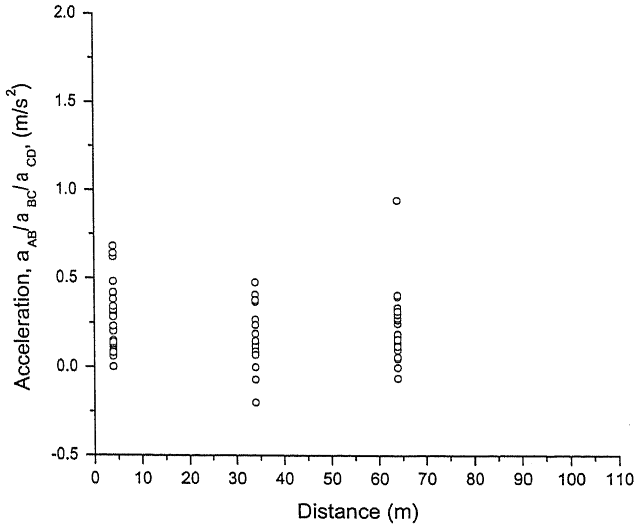


Figure 3.14: Acceleration profiles for two wheelers of H12W

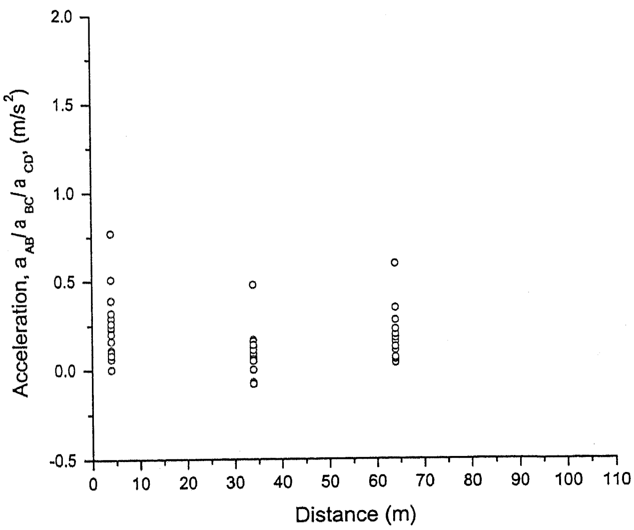


Figure 3.15: Acceleration profiles for four wheelers of H12W

Chapter 4

Analysis

In this chapter, analysis is done of the data presented in the previous chapter. The purpose of the analysis is to develop relationships between hump geometry and various hump impact parameters. This chapter is divided into six sections. The next section has a brief description of what is meant by hump geometry. The two sections after that describe relationships between hump geometry and speed at hump, and speed reduction at humps, respectively. The fourth section develops relations between hump geometry and decelerations. The fifth section describes relation between speed at hump and accelerations. The last section describes comparisons between the relationships developed here and the relationships developed by Fwa and Tan [5].

Before proceeding further, it must be mentioned that data from H12W, H10W, H10E, H8W, H8E, H22W, H22E, H21S, H21N, H18S, H18N, H19S and H19N have been used to develop the relationships. The reason for choosing these humps is because they allowed data to be collected from vehicles which are otherwise impeded. Certain other humps, like H3E, H3W, H2E, H2W, H5S and H5N could not be considered because of extremely low traffic volumes.

4.1 Hump geometry

The shape of a hump, broadly speaking, is its geometry. However, the term hump geometry is used to imply a specific shape parameter. In this section, some such parameters are described with the help of Figure 4.1.

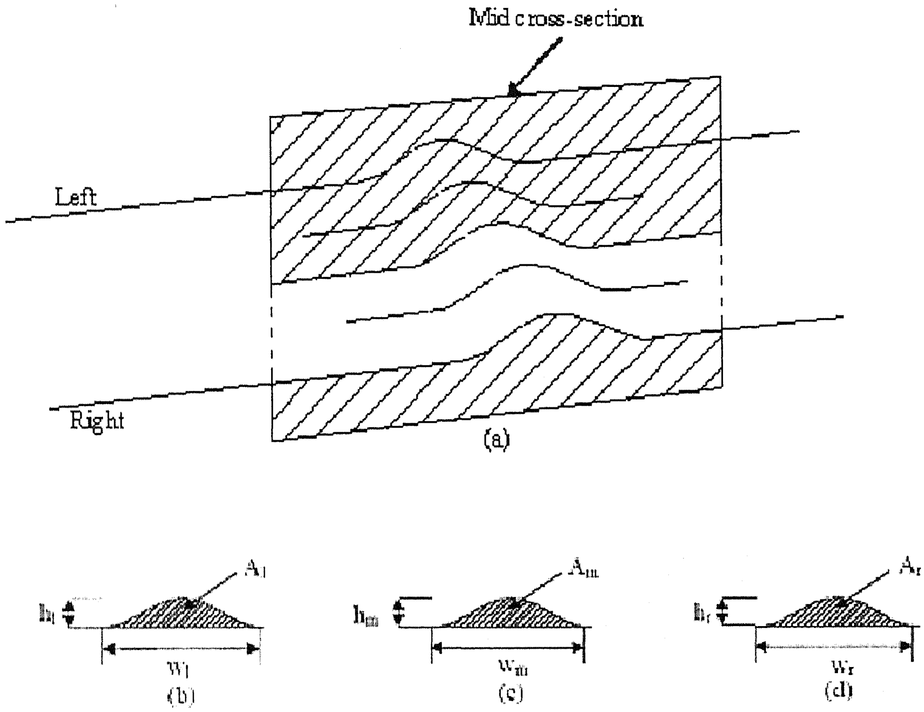


Figure 4.1: Schematic showing, (a) longitudinal profile a hump, (b) left cross-section, (c) mid cross-section, and (d) right cross-section.

Further, it must be noted that the shape parameter being looked at must be on which tends to affect the hump impact factors. A possible list of hump geometry therefore are:

1. height parameters like, h_l, h_m, or h_r.
2. shape parameters like, $h_l/2w_l$, h_m/w_m, or $h_r/2w_r$.

3. other parameters like, area to width ratio (A_l/w_l and so on) introduced by Fwa and Tan [5].

It is felt that the shape parameter which will tend to impact traffic movement must be easily perceived by the driver. Hence, Fwa and Tan's parameter is deemed unsuitable. It is therefore decided to use either a height parameter or a slope parameter. Unfortunately, all humps in the study area had the same width, hence one could not differentiate on the basis of analysis (presented later) between a slope parameter and a height parameter. Thus in this thesis a height parameter, more specifically, is used to characterize hump geometry. In the following sections, relations between h_m, (in cms) and hump impact parameters are given.

4.2 Relationship between speed at hump and hump geometry

In this section, relationship between hump geometry and the impact parameter, speed at hump, is discussed. Both average speed at hump and the 85^{th}percentile speed at hump are considered for developing the relationships.

4.2.1 Average speed

Three relationships between hump geometry and average speed at hump are proposed and evaluated. The relationships are: single regime linear, two regime linear, and single regime non-linear. These are discussed in the following subsections.

4.2.1.1 Single regime linear

Using the observations from speed profile survey, single regime linear relationships are developed between average speed at hump, S_h (in kmph) and height of hump, h_m (in

cms) for both two wheelers and four wheelers. That is, it is proposed that $S_h = a + bh_m$. This assumes that the response of driver is qualitatively same throughout whole range of heights i.e., from 2.5 cm to 7 cm. The fitted equations together with relevant statistics like R^2 and t values are given in Equation (4.1) and Equation (4.2). Figures 4.2 and 4.3 show the graphical representation of these relationships. Higher values of R^2 and strong t values imply reliable relations between speed at hump, S_h (in kmph) and hump height, h_m (in cms) for both two and four wheelers. So, it can be inferred that average speed at hump, S_h (in kmph) is appreciably dependent on height of the hump, h_m (in cms). As height of the hump, h_m (in cms) increases, average speed at hump, S_h (in kmph) decreases. It is also observed that the rate of decrease of average speed at hump, S_h (in kmph) is more for four wheelers compared to two wheelers.

For two wheelers,

$$S_h^t = 32.75 - 1.07 \times h_m \tag{4.1}$$

$R^2 = 0.71$

t-stat.: 31.1 (intercept), -5.2 (slope)

For four wheelers,

$$S_h^f = 32.85 - 1.56 \times h_m \tag{4.2}$$

$R^2 = 0.74$

t-stat.: 23.0 (intercept), -5.6 (slope)

4.2.1.2 Two regime linear

Although, single regime linear models performed well, it was felt, after looking at the data that possibly a two regime relation which assumes qualitatively different behavior for different sets of heights will perform better. It is assumed that different behaviors of driver exist for low heights (i.e. 2.5 cm to 4 cm) and for high heights (5.5 cm to 7 cm). The equation developed and their relevant statistics are shown in the following and Equations are 4.3, 4.4, 4.5 and 4.6 and the graphical representation are given in Figures 4.4 and 4.5.

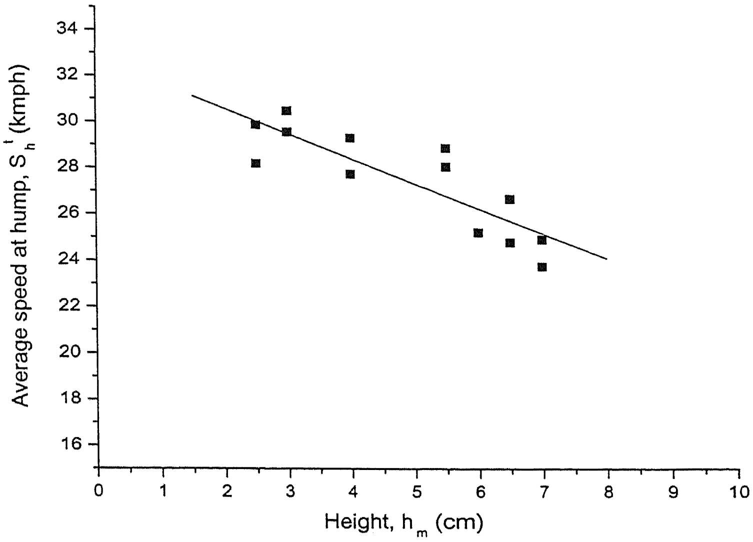


Figure 4.2: Single regime linear model for average speed at hump versus hump height for two wheelers

For two wheelers,

Regime 1 (low heights):

$$S_h^t = 30.7 - 0.48 \times h_m \tag{4.3}$$

$\mathrm{R}^2 = 0.10$

t-stat.: 13.2 (intercept), -0.7 (slope)

Regime 2 (high heights):

$$S_h^t = 42.11 - 2.54 \times h_m \tag{4.4}$$

$\mathrm{R}^2 = 0.73$

t-stat.: 9.7 (intercept), -3.7 (slope)

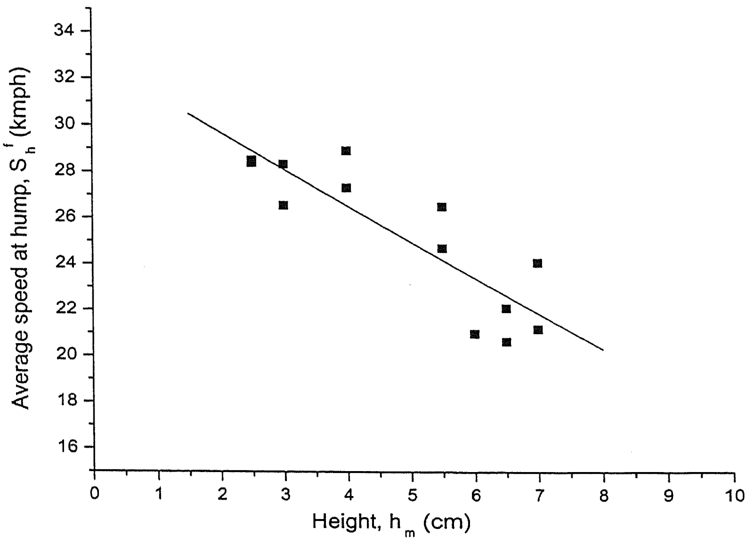


Figure 4.3: Single regime linear model for average speed at hump versus hump height for four wheelers

For four wheelers,
Regime 1 (low heights):

$$S_h^f = 28.27 - 0.07 \times h_m \tag{4.5}$$

$R^2 = 0.03$

t-stat.: 13.5 (intercept), -0.10 (slope)

Regime 2 (high heights):

$$S_h^f = 35.28 - 1.96 \times h_m \tag{4.6}$$

$R^2 = 0.30$

t-stat.: 4.2 (intercept), -1.5 (slope)

As can be seen from the results that contrary to the initial feelings the relations were statistically worse than the single regime relations. Yet, the data did suggest that, at low heights the impact of a hump does not change appreciably with height. This

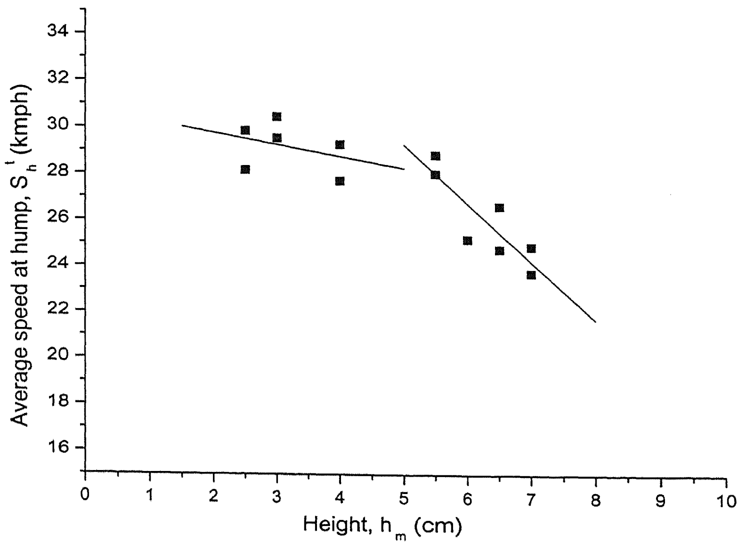


Figure 4.4: Two regime linear model for average speed at hump versus hump height for two wheelers

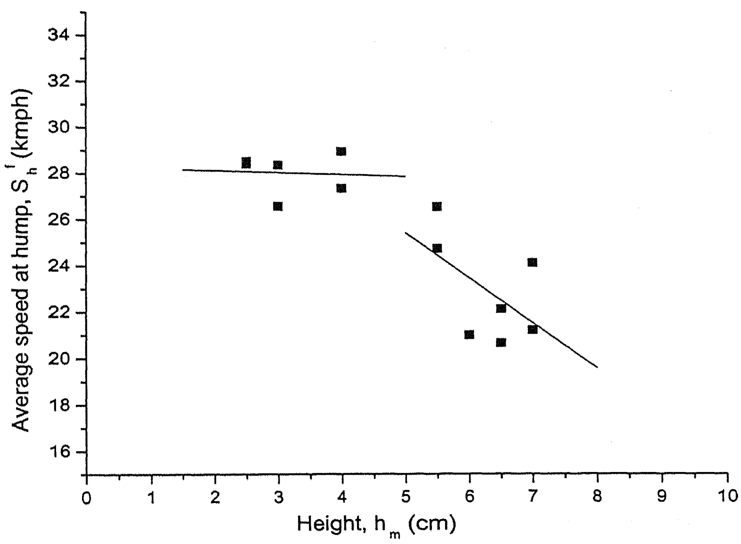


Figure 4.5: Two regime linear model for average speed at hump versus hump height for four wheelers

suggestion also does make sense as one can argue that drivers tend to ignore small humps irrespective of their specific heights. Thus in order to pursue this line of thinking a non-linear functional form is proposed.

4.2.1.3 Single regime non-linear

The following form is proposed here: $S_h = a + be^{h_m}$. As before the results are provided in Equations 4.7 and 4.8 and in Figures 4.6 and 4.7.

For two wheelers,

$$S_h^t = 29.26 - 0.005 \times e^{h_m} \tag{4.7}$$

$R^2 = 0.78$

t-stat.: 71.9 (intercept), -6.2 (slope)

For four wheelers,

$$S_h^f = 27.46 - 0.006 \times e^{h_m} \tag{4.8}$$

$R^2 = 0.61$

t-stat.: 35.8 (intercept), -4.1 (slope)

These results show that the single regime non-linear provide comparable results with single regime linear. It is felt that although the non-linear relationship better represents the notion of low impact from "small" humps, the functional form is more complex than the linear version.

4.2.2 85^{th} percentile speed

Often in traffic engineering it makes sense to look at the 85^{th}percentile speed of stream as it indicates a value of speed under which most people drive. Hence, an attempt made to relate the 85^{th}percentile speed, S_{85}, (in kmph) to h_m (in cms).

Two relationships between h_m (in cms) and the 85^{th}percentile speed at hump, S_h (in

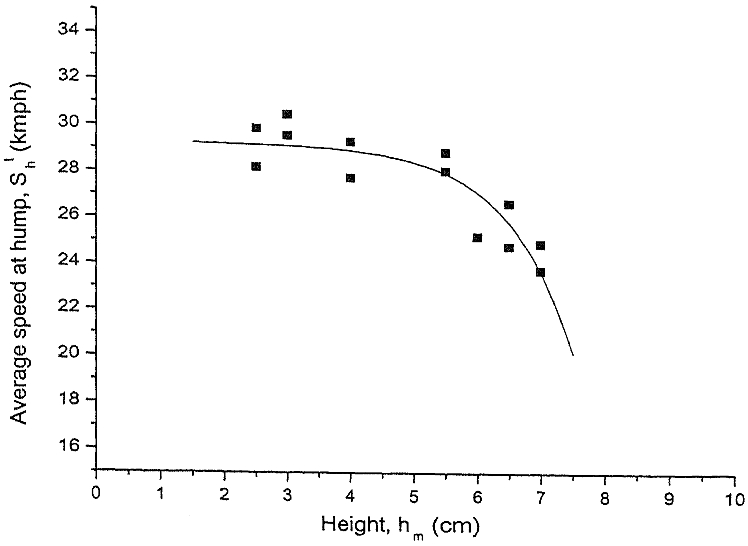


Figure 4.6: Single regime non-linear model for average speed at hump versus hump height for two wheelers

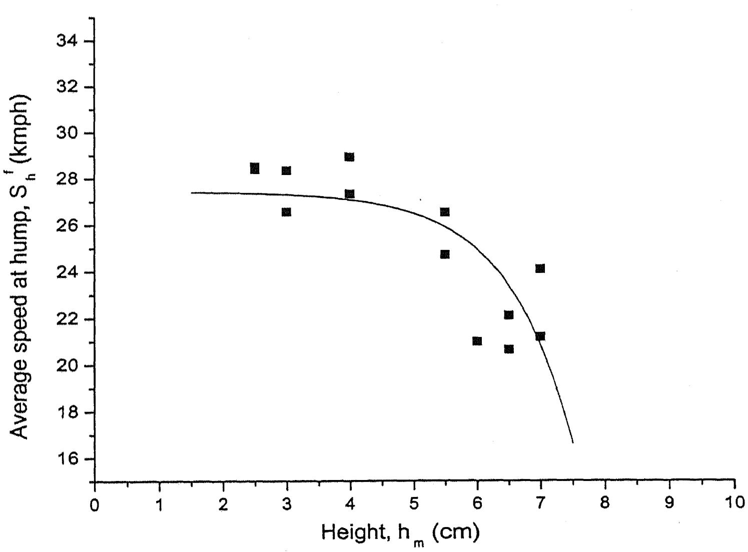


Figure 4.7: Single regime non-linear model for average speed at hump versus hump height for four wheelers

Table 4.1: Developed models for 85thpercentile speed along with R^2 and t-statistics for two and four wheelers

Vehicle type		Model type	
		Single regime linear	Single regime non-linear
Two wheeler	model	$S^t_{85} = 39.82 - 1.41 \times h_m$	$S^t_{85} = 35.2 - 0.006 \times e^{h_m}$
	R^2	0.57	0.60
	t-stat.	21.0 (intercept)	43.7 (intercept)
		-3.8 (slope)	-4.0 (slope)
Four wheeler	model	$S^f_{85} = 38.07 - 1.54 \times h_m$	$S^f_{85} = 32.14 - 0.004 \times e^{h_m}$
	R^2	0.57	0.25
	t-stat.	18.5 (intercept)	26.8 (intercept)
		-3.8 (slope)	-1.9 (slope)

kmph) are developed (Note that.two regime linear is no longer considered here). The relationships, are described in Table 4.1. Figures 4.8 through 4.11 show the results graphically. Except for the single regime non-linear model for four wheelers all others given reasonable fit with high t-values. At the same time, it must be mentioned that the variance in the 85th percentile speed data is much more than the average speed data and therefore the fits are in general worse. Not surprisingly through the intercept terms (indicating speed when there is no hump) in the present results are higher than the corresponding fits with average speed. This is because 85thpercentile speed in general (and in this case is particular) is higher than the average speed.

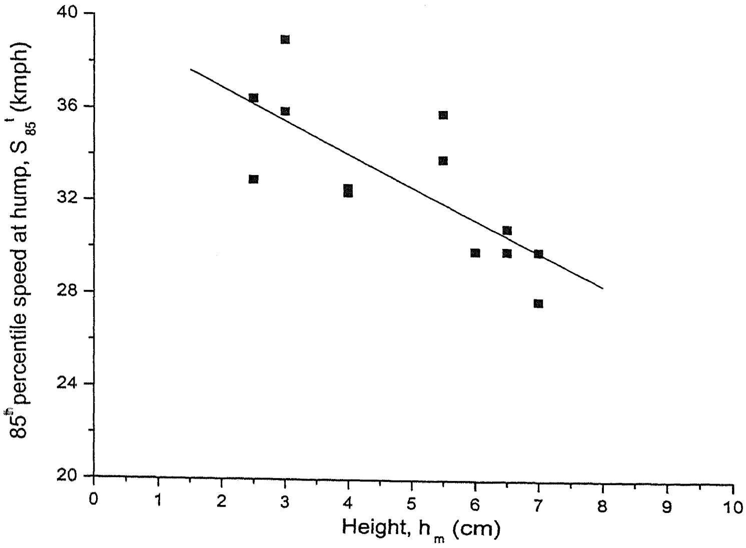


Figure 4.8: Single regime linear model for 85^{th}percentile speed versus hump height for two wheelers

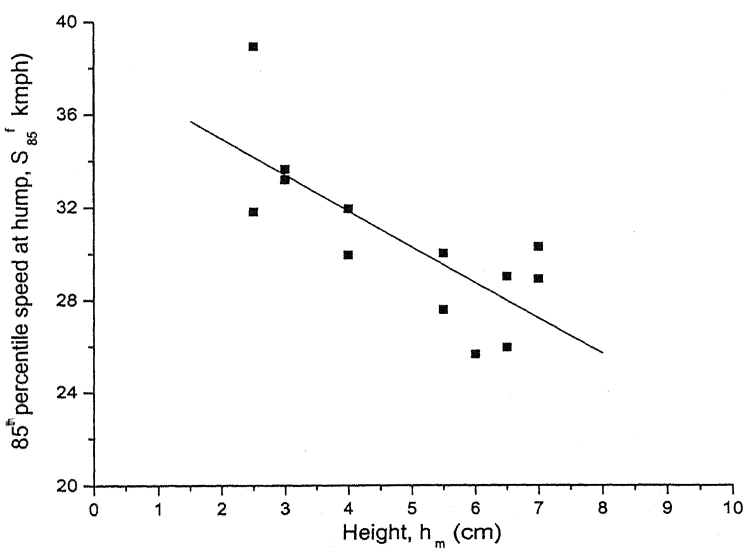


Figure 4.9: Single regime linear model for 85^{th}percentile speed versus hump height for four wheelers

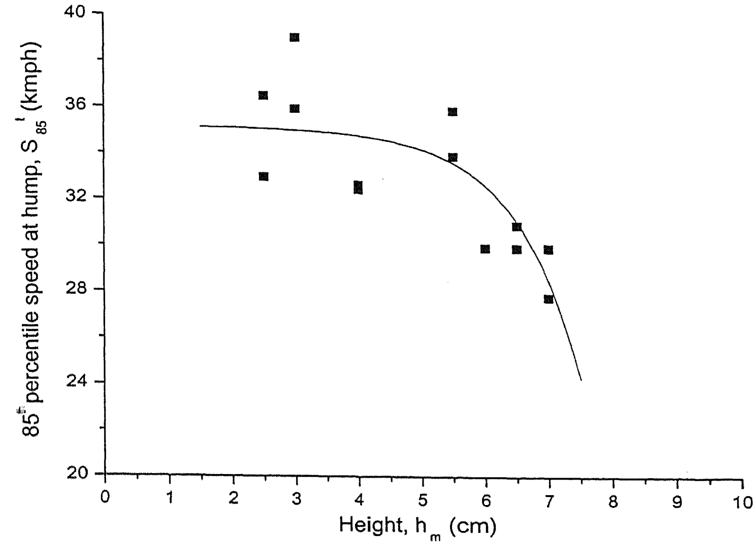


Figure 4.10: Single regime non-linear model for 85thpercentile speed versus hump height for two wheelers

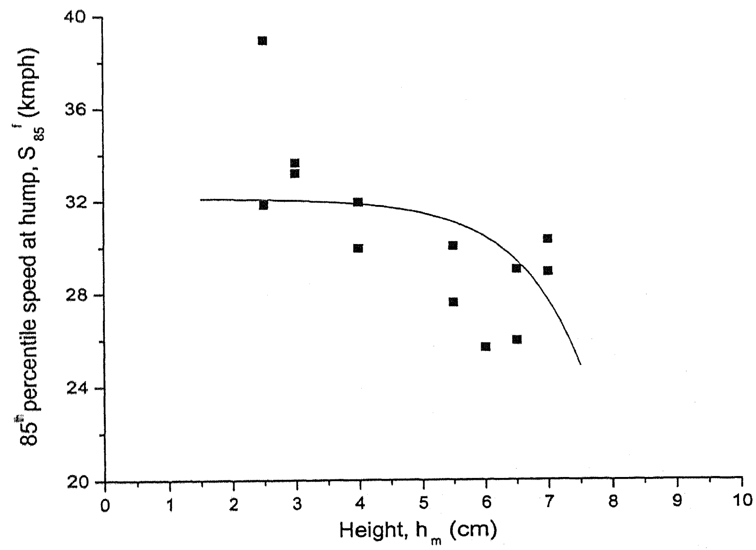


Figure 4.11: Single regime non-linear model for 85thpercentile speed versus hump height for four wheelers

Table 4.2: Developed models for average speed reduction along with R^2 and t-statistics for two and four wheelers

Vehicle type		Model type		
		Single regime linear	Single regime non-linear	Single regime linear through origin
Two wheeler	model	$S_r^t = 0.03 + 1.8 \times h_m$	$S_r^t = 6.03 + 0.008 \times e^{h_m}$	$S_r^t = 1.81 \times h_m$
	R^2	0.84	0.84	0.98
	t-stat.	0.2 (intercept)	11.3 (intercept)	
		7.6 (slope)	7.5 (slope)	24.3 (slope)
Four wheeler	model	$S_r^f = -1.69 + 2.77 \times h_m$	$S_r^f = 7.72 + 0.011 \times e^{h_m}$	$S_r^f = 2.46 \times h_m$
	R^2	0.88	0.81	0.98
	t-stat.	-1.1 (intercept)	8.7 (intercept)	
		8.9 (slope)	6.7 (slope)	24.1 (slope)

4.3 Relationship between speed reduction and hump geometry

In order to understand the impact of a hump's shape on vehicular movements, an attempt is made to relate average speed reduction, S_r, (in kmph) at humps to the hump height, h_m (in cms). The results are summarized in Table 4.2. Figures 4.12 through 4.17 shows the results graphically. As can be seen from the table, three different relations are attempted. All the relations give good results. However, note that the intercept term in the linear as well as non-linear graphs do not lend themselves to logical interpretations. Hence "through- the-origin" fit is also attempted. Note that R^2 value for "through-the-origin" fit is not comparable with the other R^2 values.

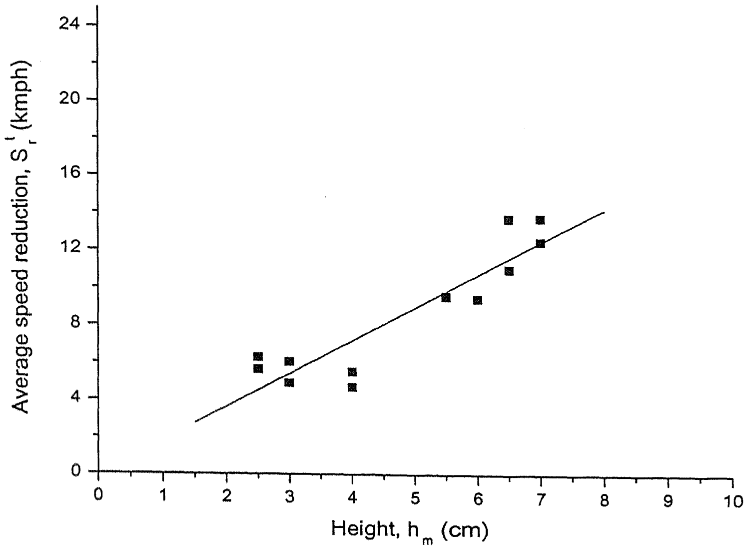


Figure 4.12: Single regime linear model for average speed reduction versus hump height for two wheelers

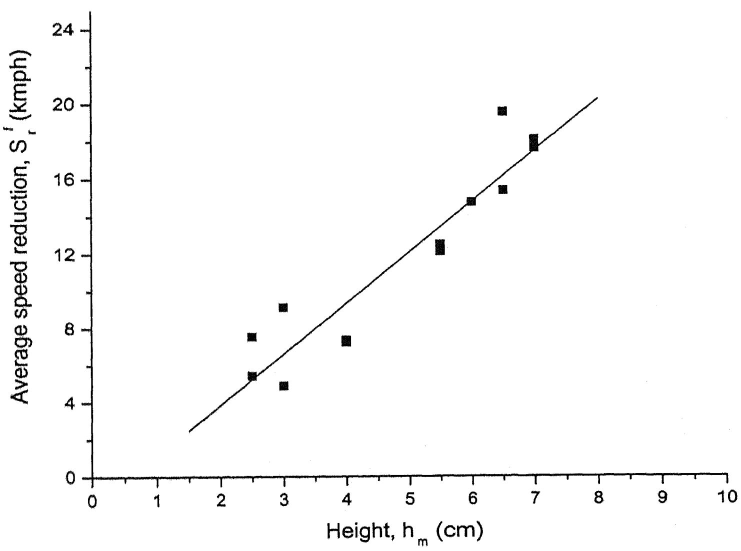


Figure 4.13: Single regime linear model for average speed reduction versus hump height for four wheelers

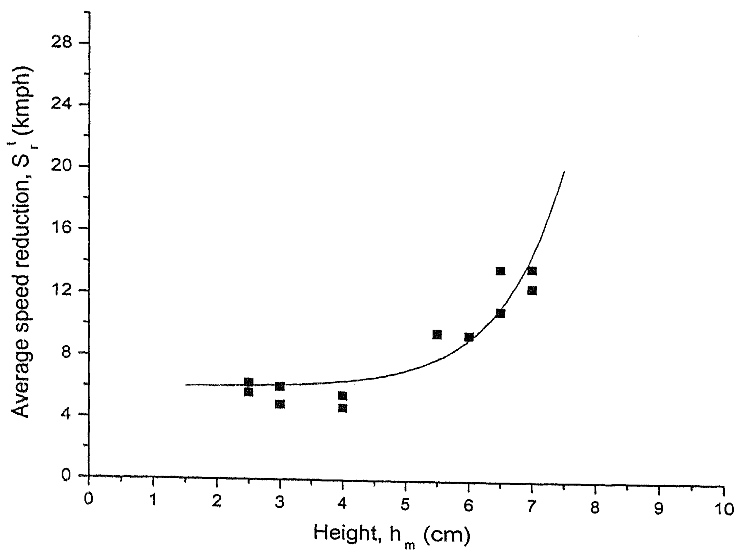


Figure 4.14: Single regime non-linear model for average speed reduction versus hump height for two wheelers

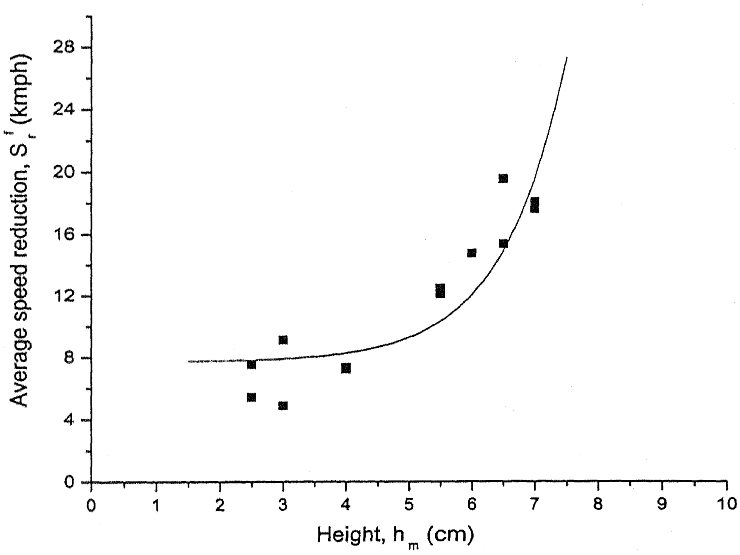


Figure 4.15: Single regime non-linear model for average speed reduction versus hump height for four wheelers

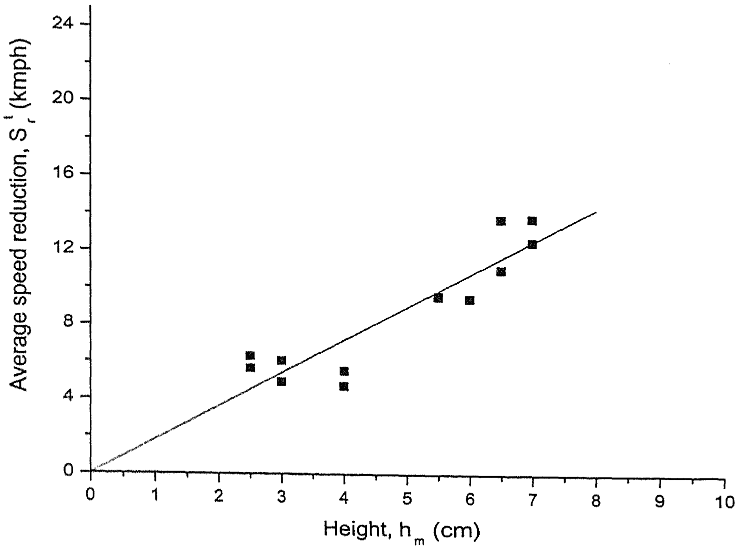


Figure 4.16: Single regime linear model through the origin for average speed reduction versus hump height for two wheelers

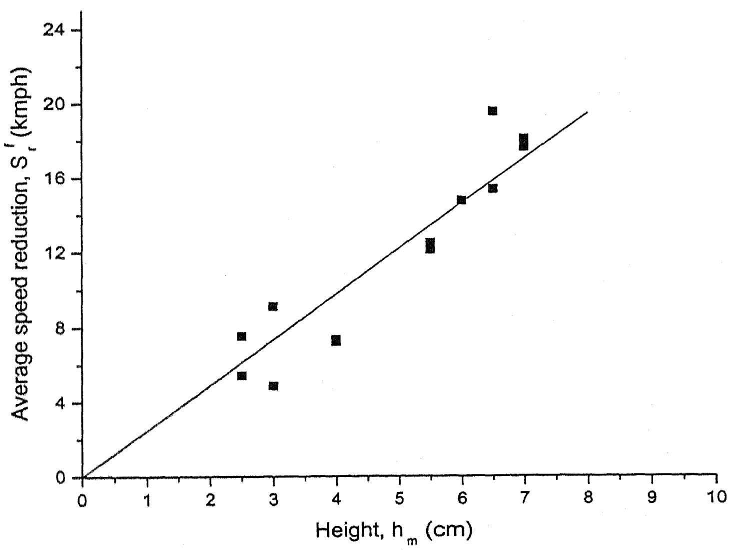


Figure 4.17: Single regime linear model through the origin for average speed reduction versus hump height for four wheelers

4.4 Relationship between deceleration and hump geometry

In this section, relationship between hump geometry, h_m and decelerations at humps is discussed. Two types of decelerations are considered, 1) is the immediate deceleration (i.e. decelerations just before the hump) and 2) the spatial average deceleration (i.e. deceleration values employed by vehicles over a longer distance while approaching the hump). Deceleration d_{CD}, (in m/s^2) is taken as the first quantity and deceleration d_{AD}, (in m/s^2) is taken as the second quantity. It may be recalled that Point A is 75 m upstream of the hump, C is 25 m upstream of the hump and D is immediately after the hump.

4.4.1 Relationship between deceleration, d_{CD} and h_m

Based on the general observation of the data a linear relation is fitted to the data. The results are tabulated in Table 4.3. As can be seen from the table, there are two linear relations, the first one with the intercept and the other is without. The reason for using the "without intercept" form is that the t-values for the intercept term in the first relation are low. In these cases it is suggested that the second relation be used. The results are graphically depicted in Figures 4.18 to 4.21. An interesting point to be noted here is that four wheelers (despite being bigger vehicles) tend to get more affected by humps and decelerates more.

4.4.2 Relationship between deceleration, d_{AD} and h_m

As in the previous section, the results are tabulated in Table 4.4. Figures 4.22 to 4.25 show the results graphically. As is expected the slopes are smaller than the corresponding d_{CD} versus h_m (in cms) relations. (This is expected because the spatial average deceleration will be less than the immediate deceleration). What is interesting

Table 4.3: Developed models for deceleration, d_{CD} along with R^2 and t-statistics for two and four wheelers

Vehicle type		Model type: Single regime linear with intercept	Model type: Single regime linear without intercept
Two wheeler	model	$d^t_{CD} = 0.14 + 0.07 \times h_m$	$d^t_{CD} = 0.09 \times h_m$
	R^2	0.82	0.98
	t-stat.	1.7 (intercept)	
		4.2 (slope)	14.8 (slope)
Four wheeler	model	$d^f_{CD} = -0.07 + 0.16 \times h_m$	$d^f_{CD} = 0.15 \times h_m$
	R^2	0.77	0.96
	t-stat.	-0.3 (intercept)	
		3.6 (slope)	10.9 (slope)

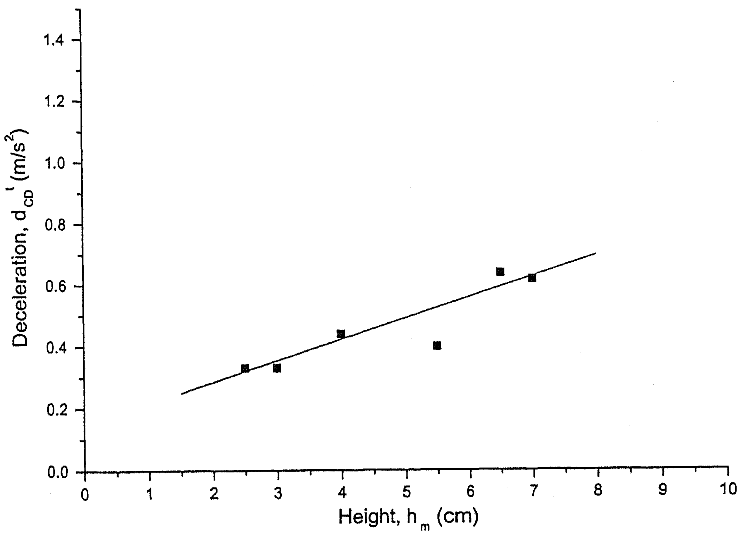


Figure 4.18: Single regime linear model with intercept for deceleration and hump height for two wheelers

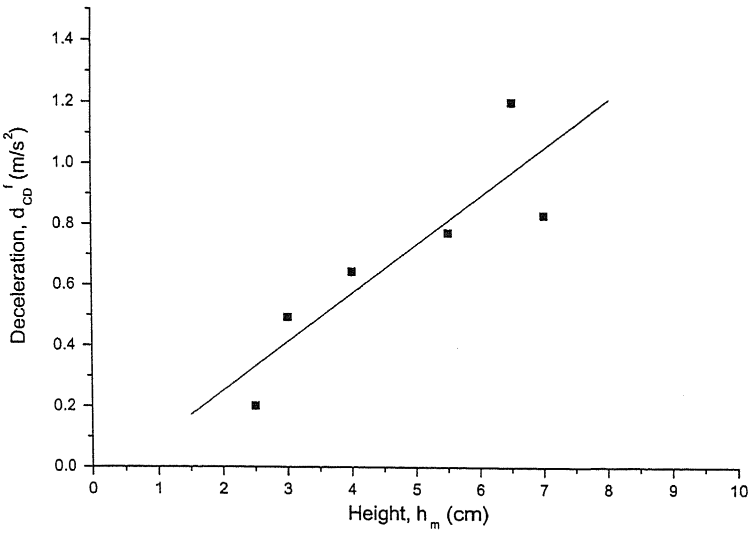


Figure 4.19: Single regime linear model with intercept for deceleration versus hump height for four wheelers

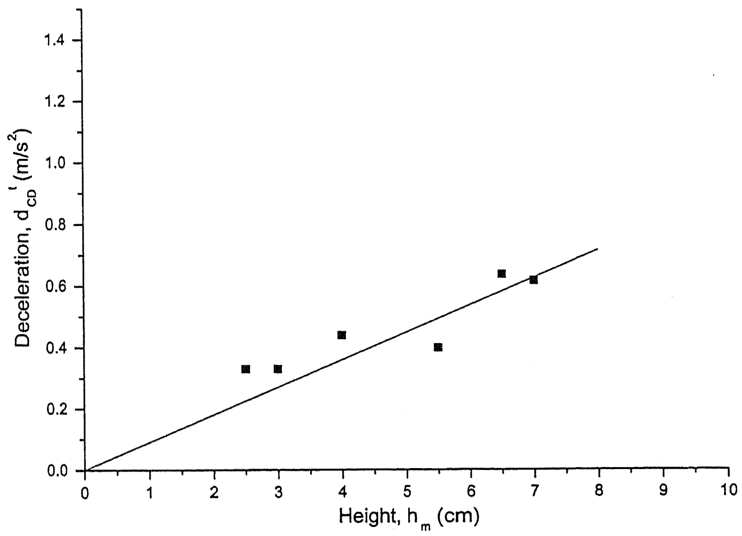


Figure 4.20: Single regime linear model without intercept for deceleration versus hump height for two wheelers

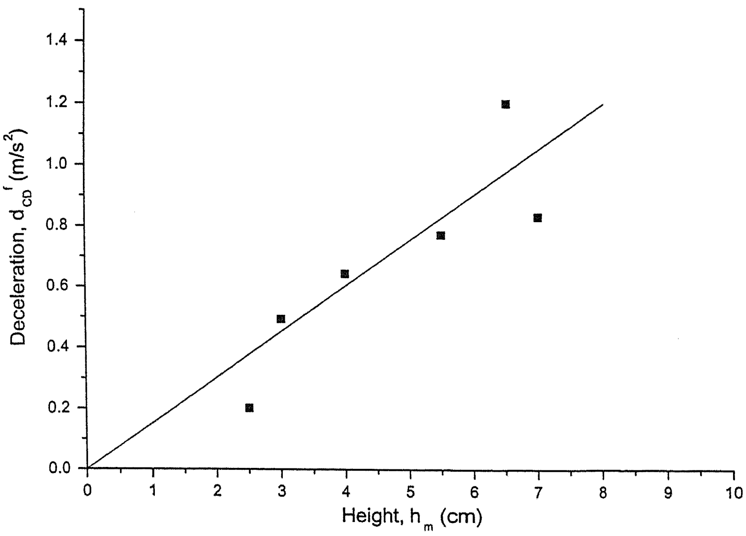


Figure 4.21: Single regime linear model without intercept for deceleration versus hump height for four wheelers

is that the slopes for both the two wheelers and four wheelers are approximately half of the slopes in d_{CD}, (in m/s^2) versus h_m (in cms) relations. This indicates that average decelerations are generally half of the immediate decelerations.

Table 4.4: Developed models for deceleration, d_{AD} along with R^2 and t-statistics for two and four wheelers

Vehicle type		Model type	
		Single regime linear with intercept	Single regime linear without intercept
Two wheeler	model	$d^t_{AD} = 0.075 + 0.036 \times h_m$	$d^t_{AD} = 0.05 \times h_m$
	R^2	0.76	0.97
	t-stat.	1.5 (intercept)	
		3.6 (slope)	13.3 (slope)
Four wheeler	model	$d^f_{AD} = -0.01 + 0.08 \times h_m$	$d^f_{AD} = 0.08 \times h_m$
	R^2	0.77	0.96
	t-stat.	-1.24 (intercept)	
		3.6 (slope)	11.7 (slope)

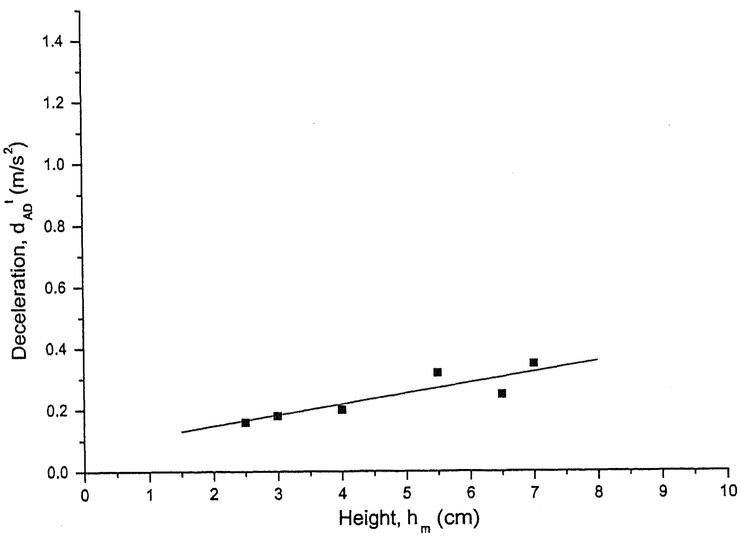


Figure 4.22: Single regime linear model with intercept for deceleration versus hump height for two wheelers

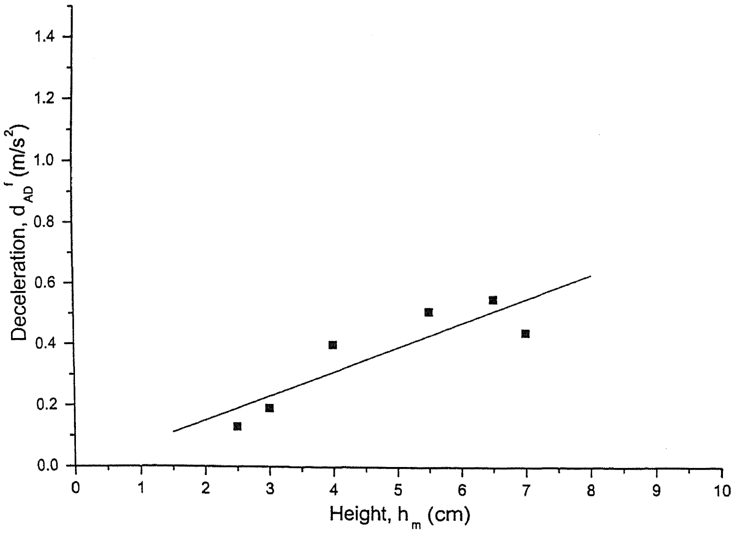


Figure 4.23: Single regime linear model with intercept for deceleration versus hump height for four wheelers

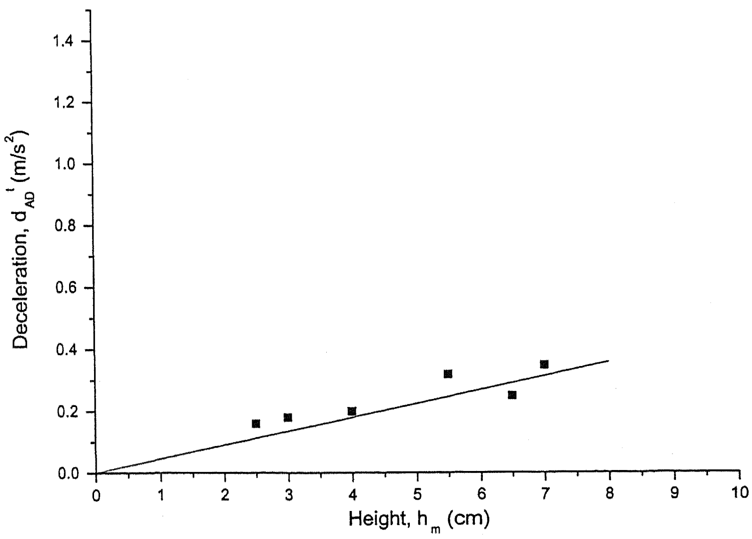


Figure 4.24: Single regime linear model without intercept for deceleration versus hump height for two wheelers

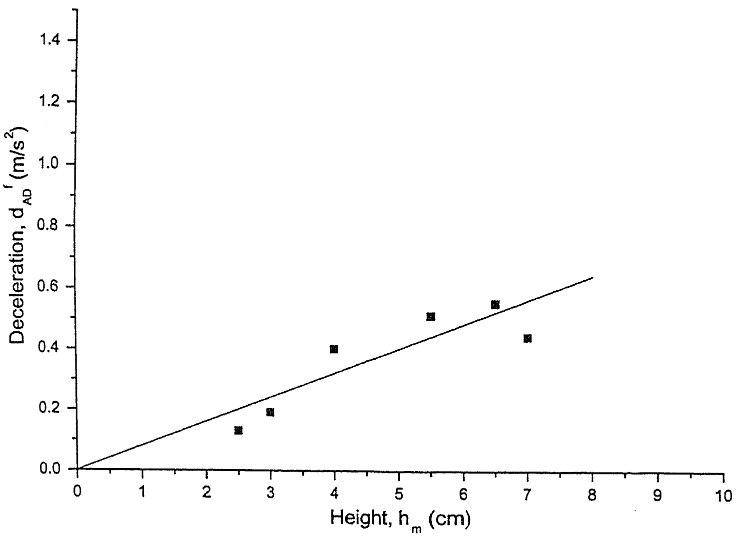


Figure 4.25: Single regime linear model without intercept for deceleration versus hump height for four wheelers

4.5 Relationship between acceleration and speed at hump

An attempt was made to relate accelerations near humps to the hump geometry. No statistically some relation could be determined. The reason could be that accelerations over after crossing the hump and hence the humps height may not be directly impacting the choice of acceleration values. It was realized that there may not be any good relation between acceleration and any parameter related to humps; the sole factor that may have some bearing with acceleration values is the speed of vehicle at the end of hump.

As in the case of deceleration, have also two different acceleration values are looked at, 1) immediate acceleration, a_{AB}, (in m/s^2) and 2) average acceleration, a_{AD}, (in m/s^2). Recall that, Point A is the end of the hump, B is 30 m from A and D is 100 m from A. All the results obtained are tabulated in Table 4.5. In this case, only one type of relation has been attempted. As can be seen from the table none of the relations are

Table 4.5: Developed relations for acceleration, a_{AB} and a_{AD} along with R^2 and t-statistics for two and four wheelers

Vehicle type		Relation with a_{AB}	Relation with a_{AD}
Two wheeler	model	$a^t_{AB} = 0.82 - 0.02 \times S_h$	$a^t_{AD} = 0.53 - 0.012 \times S_h$
	R^2	0.55	0.17
	t-stat.	2.6 (intercept)	1.0 (intercept)
		-1.9 (slope)	0.6 (slope)
Four wheeler	model	$a^f_{AB} = 0.79 - 0.02 \times S_h$	$a^f_{AD} = 0.41 - 0.009 \times S_h$
	R^2	0.45	0.1
	t-stat.	2.4 (intercept)	1.7 (intercept)
		-1.6 (slope)	-0.8 (slope)

statistically strong; although relations with a_{AB}, (in m/s^2) are better in this regard that relations with a_{AD}, (in m/s^2). The results are graphically shown in Figures 4.26 to 4.29.

4.6 Comparisons between the proposed model and Fwa and Tan's model

Search of existing literature yielded only one study by Fwa and Tan [5] where a relationship between speed at hump and hump geometry has been developed. Fwa and Tan [5] developed two relations referred here as FT-linear and FT-non-linear.

The FT-linear form is

$$V = a + b\frac{A_m}{w_m}$$

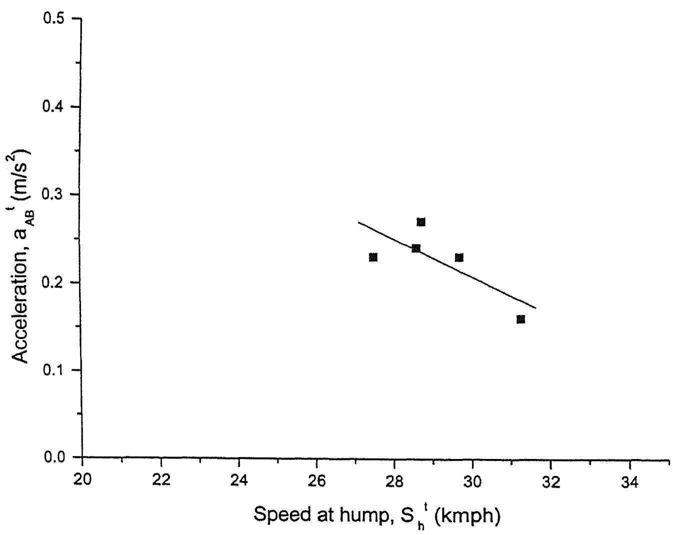


Figure 4.26: Single regime linear model for acceleration versus hump height for two wheelers

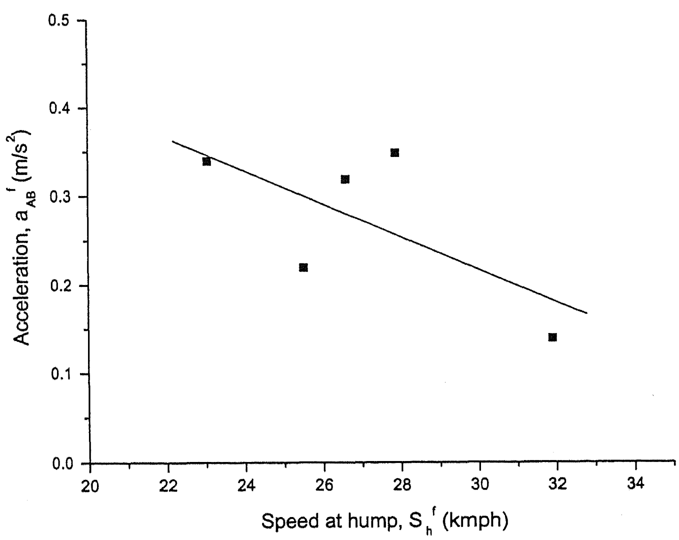


Figure 4.27: Single regime linear model for acceleration versus hump height for four wheelers

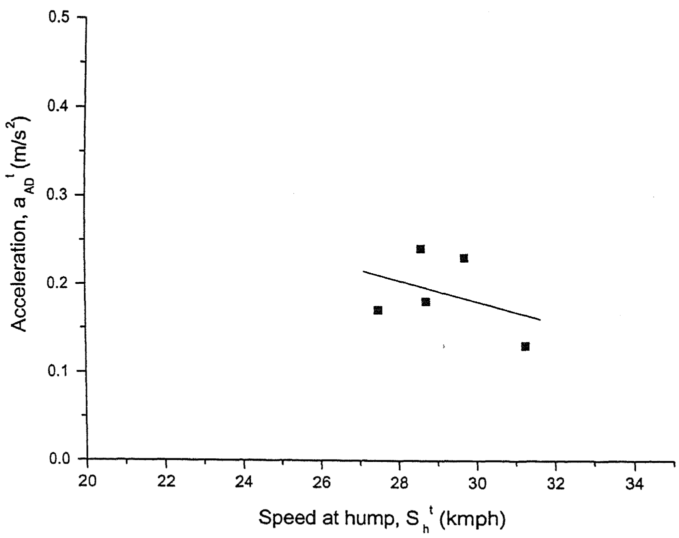


Figure 4.28: Single regime linear model for acceleration versus hump height for two wheelers

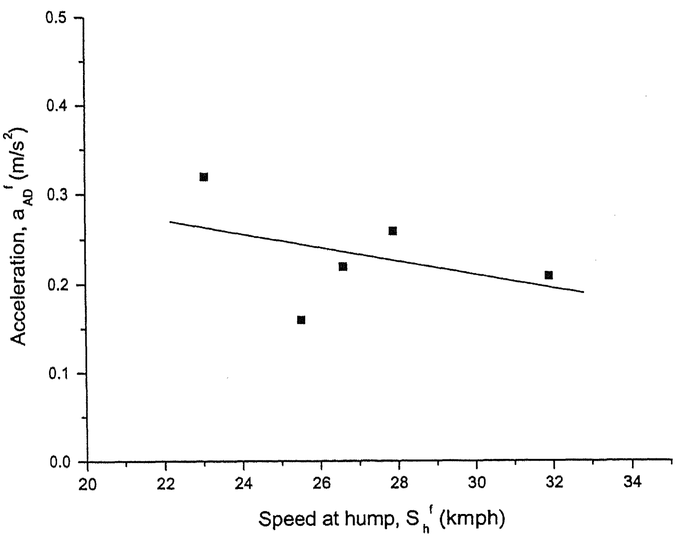


Figure 4.29: Single regime linear model for acceleration versus hump height for four wheelers

where V is either the average speed at hump, S_h (in kmph) or the 85^{th}percentile speed at hump, S_{85} (in kmph) ; and a and b are constants which depend on whether V is S_h or S_{85}.

The FT-non-linear form is

$$\frac{1}{V} = c + d\frac{A_m}{w_m}$$

where V is either the average speed at hump, S_h (in kmph) or the 85^{th}percentile speed at hump, S_{85} (in kmph) ; and a and b are constants which depend on whether V is S_h or S_{85}.

In order to compare, Fwa and Tan's predictions with those from proposed models, the following procedure is used. First, FT-linear and FT -non-linear models fitted to data collected in the present study. Second, the predicted values from the fitted FT-linear and FT-non-linear models compared with the observed values. Third, the predicted values from the proposed models are also compared with the observed values. Fourth, results from the these comparisons are then used to comment on the effectiveness of the models.

Figures 4.30 and 4.31 shows the predicted value versus observed value plots for cases where observed values are average speeds of two wheelers (Figure 4.30) average speed of four wheelers (Figure 4.31) The predicted values are obtained using proposed linear, proposed non-linear, FT-linear, and FT-non-linear. The line in the figure is 45 degree line indicating where the points should have been had the predictions been accurate.

As can be seen from the figures FT-non-linear is not a good model. The performance of FT-linear is comparable with the proposed linear and non-linear models. Since h_m is of much easier parameter to determine than (A_m/w_m) it is felt that proposed linear and proposed non-linear are better ones than non-linear.

Figures 4.32 and 4.33 shows the predicted value versus observed value plots for cases where observed values are 85^{th}percentile speeds of two wheelers (Figure 4.32) 85^{th}percentile

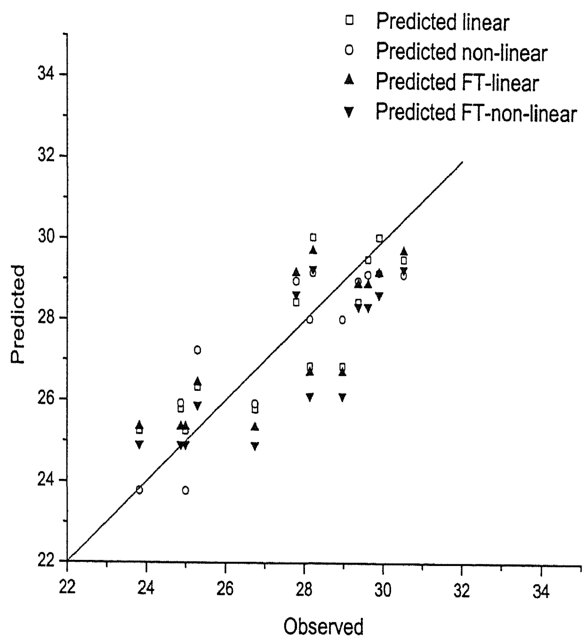


Figure 4.30: Comparison of observed versus predicted for average speed at hump for two wheelers

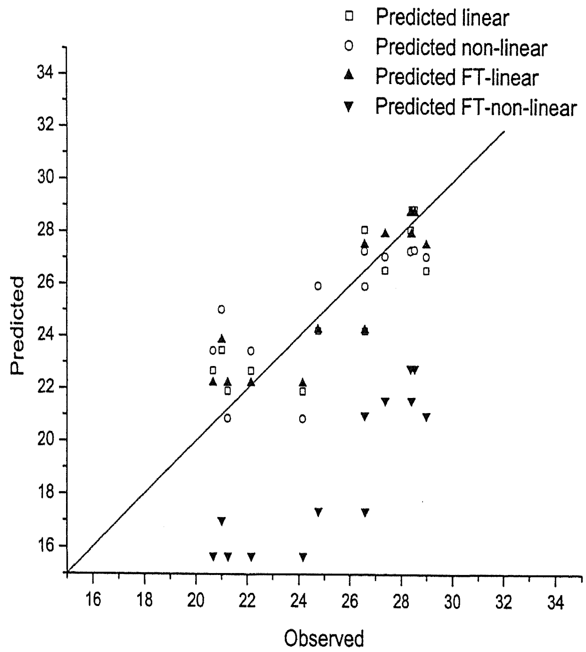


Figure 4.31: Comparison of observed versus predicted for average speed at hump for four wheelers

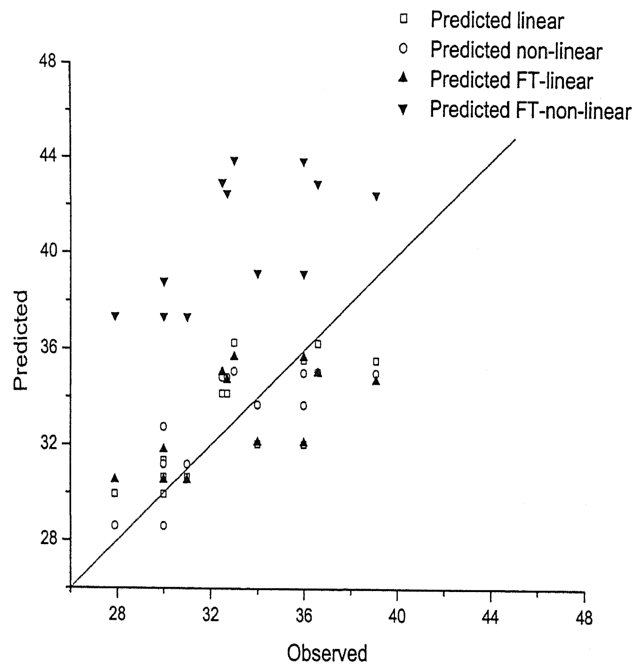


Figure 4.32: Comparison of observed versus predicted for 85^{th}percentile speed at hump for two wheelers

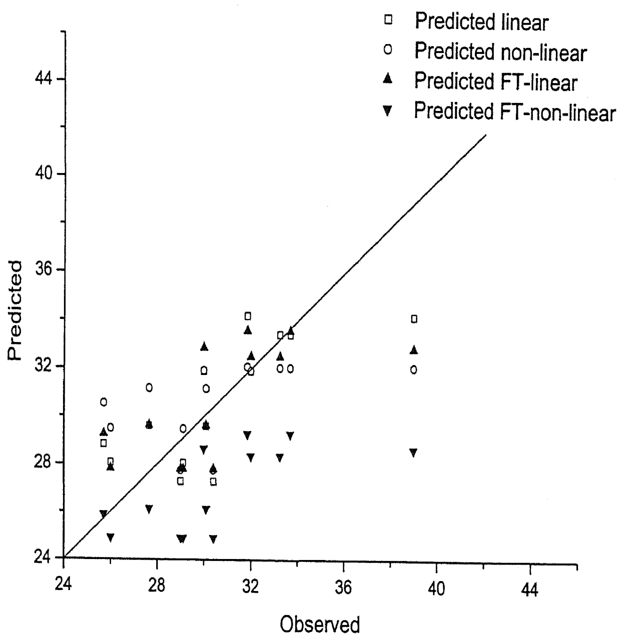


Figure 4.33: Comparison of observed versus predicted for 85^{th}percentile speed at hump for four wheelers

speeds of four wheelers (Figure 4.33). The predicted values are obtained using proposed linear, proposed non-linear, FT-linear, and FT-non-linear. The line in the figure is 45 degree line indicating where the points should have been had the predictions been accurate.

The observations regarding the performance of the various models made for Figures 4.30 and 4.31 are equally applicable here.

In order to quantify the observations made from Figures 4.30 to 4.33, Table 4.6 is developed. This table gives the root mean square error of all the four models when used to predict 1) average speed of two wheelers, 2) average speed of four wheelers, 3) 85^{th}percentile speed of two wheelers, and 4) 85^{th}percentile speeds of four wheelers. As seen from the table FT-non-linear is by far the worst model. The performance of other three are comparable, although the proposed models seem to be slightly better. This fact together with the fact that the proposed models use a simple parameter to quantify hump geometry makes the proposed model some what superior to FT-linear model

Table 4.6: Comparison of root mean square errors of models developed in present study and developed by Fwa and Tan

Predicted quantity	Type of vehicle	Proposed		Fwa and Tan	
		Linear	Non-linear	Linear	Non-linear
Average speed	Two wheelers	1.13	1.0	1.21	1.37
	Four wheelers	1.54	1.88	1.38	6.58
85^{th}percentile speed	Two wheelers	2.04	1.98	2.30	7.84
	Four wheelers	2.22	2.95	2.47	4.43

Chapter 5

Conclusions

In this thesis an attempt made, to relate the hump geometry to the impact a hump has on vehicular traffic. It is seen that hump height is good parameter for characterizing hump geometry. The impact of a hump may be characterized through the following parameters:(i) speed at humps, (ii) extent of speed reduction at humps, (iii) discomfort at humps, (iv) decelerations while approaching hump, (v) accelerations after crossing the hump, and (vi) impact zone. Owing to the non-availability of certain equipment as well as ideal site for measurement of data on hump parameter like driver discomfort and the impact zone of a hump could be studied. The rest of the impact parameters have been, where possible, related to hump geometry. During this exercise, the following observations were made

1. Average speed of hump could be related strongly to height of the hump using a simple linear relation ship.

2. Although the data suggested that vehicles behave differently at low high height humps than high height humps. Attempts at deriving two regime model proved two type. Later a non-linear relationship which captured the difference behavior was fitted to the data. The statistical parameter showed that in general these models behaved more or less similarly to the linear model.

3. The data on 85^{th}percentile speed, as expected, had much greater variability than the average speed. Consequently, the relationships between 85^{th}percentile speed and hump height were not as strong.

4. Speed reductions at humps showed a much stronger relationship with hump height. This may indicate while approaching a hump, drivers feel the need to reduce their speed by certain amount than to reduce their speed by certain value.

5. Deceleration values employed while approaching hump also show a strong correlation with height. Statistical analysis suggested that the best relation between deceleration and hump height is linear one without intercept. The fact that deceleration values strong correlation corroborates the previous observation.

6. While trying to relate accelerations after the hump to the hump height no relationship could be found. This is possibly because accelerations occur after the hump has been crossed and as such depend more on the speed of vehicle at the end of hump rather than hump. In order to test this hypothesis, various relations between accelerations and speed ta hump were tried out. Unfortunately, none of the relationships turned to be a strong one.

7. The results obtained from the proposed models and obtained from similar relationships (speed at hump and hump geometry) developed by Fwa and Tan [5] were compared. It is felt that the given relations, because of their slightly improved accuracy and greater simplicity, are better.

It is felt that the fact that a single humps causes to drivers to decelerate at certain value rather than attain a certain speed is an important finding. This indicates that placing of hump a single hump may not be very effective in bringing speeds down to a certain value. More studies on hump spacings (alternatively, the impact zone of a hump) impact on average on a highway is required to study whether or how few humps together can impact zone.

It is also felt that the relationships developed here may be helpful in designing humps which have desired effect on traffic movement.

The lack of any study on the effect of hump shape as well as lack of studies on the effect of humps on driver discomfort remained the two important short comings.

Bibliography

[1] Watts, G. R. (1973). " Road humps for the control of vehicle speeds." TRRL Laboratory Report 597, Transport Road and Research laboratory, Crowthrone, Berkshire.

[2] Baguley, C. (1981). " Speed control humps-further public road trials." TRRL Laboratory Report LR1017, Transport and Road Research Laboratory, Crowthrone.

[3] Webster, D. C. (1993). " Road humps for controlling vehicle speeds." TRL project Report 18, Transport Research Laboratory, Crowthrone, Berkshire.

[4] Lines, C. J. (1993). " Road humps for the control of vehicle speeds." Traffic Engineering and Control, 34, n 1, p 2-7.

[5] Fwa, T. F., and Tan, L. S. (1993). "Geometric Characterization of Road Humps for Speed-Control Design." Journal of Transportation Engineering, 118, n 4, p 593-598.

[6] Webster, D. C.and Mackie, A. M. (1996). "Review of traffic calming schemes in 20mph zones." TRL Report 215, Transport Research Laboratory, Crowthrone, Berkshire.

[7] IRC 99 (1996). "Tentative guidelines on the provision of speed breakers for control of vehicular speeds on minor roads."

[8] Barbosa, H., Tight, M. R., and May, A. D. (2000). "A model of speed profiles for traffic calmed roads." Transportation Research. Part A, Policy Practice, 34, p103-123.